THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

AD904778

Program to Develop High Strength Aluminum Powder Metallurgy Products

Phase III -- Scale Up A

Final Report

Reported by: W. S. Cebulak
D. J. Truax
Alcoa Research Laboratories
Physical Metallurgy Division

ALCOA

Report for: January 21, 1971 to
March 20, 1972

DDC

U. S. Army
Frankford Arsenal
Contract DAAA25-70-C0358

A Department of the Army
Manufacturing Methods
and Technology Project

September 29, 1972

18 NOV 1972

U S Army,
Frankford Arsenal, attn: SMUFA-L3300
Philadelphia, Pa. 19137

ALUMINUM COMPANY OF AMERICA

P. O. BOX 2970 · PITTSBURGH, PA. 15230

ALCOA TECHNICAL CENTER

ALCOA

September 29, 1972

U. S. ARMY
FRANKFORD ARSENAL
CONTRACT DAAA 25-70-C0358

PROGRAM TO DEVELOP HIGH STRENGTH ALUMINUM POWDER METALLURGY PRODUCTS

PHASE III - SCALE-UP A

FINAL REPORT

For the Period January 21, 1971
to March 2?, 1972

W. S. Cebulak — 10-2-72
W. S. Cebulak
Project Engineer

D. J. Truax — 10-2-72
D. J. Truax
Project Engineer

J. P. Lyle Jr. — 10-2-72
J. P. Lyle Jr.
Project Supervisor

FOREWORD

This report presents the results of investigations conducted under a Manufacturing Methods and Technology Contract with the U. S. Army, administered by Messrs Harold Markus and Donald H. Kleppinger at Frankford Arsenal. This contract was funded jointly by the Aviation Systems Command (AVSCOM), St. Louis; the Munitions Command (MUCOM), Dover, New Jersey; and the Production Equipment Agency (PEQUA), Rock Island, Illinois.

SYNOPSIS

Wrought products from 170-lb aluminum alloy powder compacts have been fabricated and evaluated against three combinations of properties. Product forms included extrusions, die forgings, hand forgings, plate and sheet. Properties of interest included strength, ductility, fracture toughness, stress-corrosion cracking resistance, exfoliation corrosion resistance, and smooth and notched specimen fatigue performance.

Alloy MA66 extrusions met Target B properties:

	Target B Properties	Measured Properties Al-8.0 Zn-2.5 Mg-1.0 Cu
Y.S. - ksi	85	84.2
K_{Ic} - ksi$\sqrt{in.}$	26	28
SCC - ksi (sustained stress)	25	25
Fatigue Limit - ksi (K_t = 3, R = 0.0)	14	18.5
Exfoliation	Immune	Resistant
Elongation - %	11	11.2

MA66 and MA67 extrusions approached the property objectives of Target A, with the exceptions noted:

		Measured Properties	
	Target A Properties	MA67: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co	MA66: Al-8.0 Zn-2.5 Mg-1.0 Cu
Y.S. - ksi	95	95.9	94.3
K_{Ic} - ksi$\sqrt{in.}$	26	17	26
SCC - ksi (sustained stress)	25	25	<25
Fatigue Limit - ksi (K_t = 3, R = 0.0)	14	20	20
Exfoliation	Resistant	Resistant	Resistant
Elongation - %	11	7.8	8.0

Properties quoted above were obtained on materials which were fabricated by the argon preheating method that was optimized in Phase I.[4] Late in Phase III, dramatic improvements in longi-

tudinal and transverse fracture toughness (25 and 100% increases, respectively) were achieved by vacuum preheating and hot pressing (VAC process) prior to hot working. With the VAC process, a P/M high purity Al-8.0 Zn-2.5 Mg-1.0 Cu alloy achieved better transverse ductility and fracture toughness than ingot metallurgy (I/M) 7050 and 7075 extrusions.

Fine (15 μM APD) powders with irregular shapes resulted in better ductility and toughness in extrusions than medium (23 μM) and coarse (50 μM). Extrusions made from irregular-shaped, air atomized powder were superior to smooth, regular-shaped powders atomized with inert gases.

Fine, irregular-shaped powders resulted in better forgeability and better properties in hand forgings (open die) than coarse powders. Transverse toughness improved with increasing amounts of hot reduction. Forgeability and properties were improved by preheating compacts in argon or nitrogen instead of air.

Alloy MA67 achieved a superior combination of strength and SCC resistance in die forgings, plate and hand forgings compared to I/M 7050 and 7075 alloys, while all the P/M alloys tested were superior to 7075. However, the P/M wrought products fabricated without vacuum preheating and hot pressing were generally inferior in fracture toughness to 7075.

Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

List of Tables

List of Tables (Continued)

List of Tables (Continued)

List of Tables (Continued)

List of Tables (Continued)

List of Tables (Continued)

List of Tables (Continued)

List of Figures

List of Figures (Continued)

List of Figures (Continued)

List of Figures (Continued)

List of Figures (Continued)

List of Figures (Continued)

List of Tables - Appendix

INTRODUCTION

An Alcoa Research Laboratories investigation for the U.S. Army completed in 1966 developed aluminum powder metallurgy alloys having combinations of high strength and resistance to stress-corrosion cracking (SCC) which were superior to those of conventional aluminum alloys.[1,2,3] These alloys were superior to alloy 7075 and variants of 7075, which had the best combinations of strength and stress-corrosion cracking resistance commercially available at that time. In addition to the alloys developed, the earlier study also developed a process for fabricating P/M (Powder Metallurgy) atomized alloy extrusions which had ultrasonic quality at least equal to that of conventional aerospace materials.

The current investigation, proposed to the U.S. Army in 1968, is intended to scale up these P/M developments and to fabricate and evaluate aluminum P/M wrought products. Phase I of this program, initiated in January 1970 and completed on January 20, 1971, was a process optimization study on 15-20 lb compacts that defined some process limitations for fabricating high quality hand forgings from inert gas preheated and hot pressed compacts.[4] Phase II of this program, initiated in January 1970 and completed on April 20, 1971, was an alloy optimization study aimed at developing P/M alloy extrusions with superior combinations of high strength, fracture toughness, SCC resistance, exfoliation corrosion

resistance and fatigue performance when compared to commercial alloys.[5]

In Phase II, alloys with optimum combinations of properties met target properties except as follows: Target A (Table 1), all properties except toughness and stress-corrosion cracking resistance; Target B (Table 2), all properties; Target C (Table 3), all properties except fracture toughness.

An alloy under study in an Alcoa-funded development had shown capability of meeting Target A strength and stress-corrosion cracking resistance targets (Table 4), but fracture toughness was lower than the Target A goal.[6]

On the basis of these results, Phase III (the subject of this final report) was initiated to scale up to 170-lb compacts and to evaluate wrought products made from them.

The goals of Phase III were: (1) to evaluate alloys capable of meeting Targets A and B in scaled-up wrought products, (2) to study factors affecting fracture toughness in anticipation of improving fracture toughness for Targets A and C, and (3) to study processing factors expected to affect forgeability in hand forging of the scaled-up compacts. The alloy meeting Target B property objectives (Table 2) and the alloy with the strength and SCC requirements of Target A (Table 4) were selected for scaled-up product evaluation in Phase III. A variation of this latter alloy without cobalt was also included to achieve improved fracture toughness.

Wrought products fabricated from 170-lb compacts fcr evaluation included extrusions, die forgings, hand forgings, plate and sheet. Discussion of fabrication and properties in this report is grouped by product in the above order.

The report on the study of factors affecting fracture toughness is principally in the section relating to extrusions because this was the product used for most of this work. In addition, some of the fabricating variations studied in forgeability of hand forgings affected fracture toughness, and this information is presented in the section devoted to hand forgings.

The discussion on forgeability vs processing is discussed under hand forgings, the test vehicle in this study.

Since new commercially available alloys 7050 and 7049 with superior strength and stress-corrosion cracking resistance compared to 7075 alloy have become available recently, comparisons between the P/M wrought products and 7050 and 7049 alloys will be included where published information exists on comparable product forms.

Following these product-related discussions, a summary of conclusions is presented.

A glossary of terms and abbreviations is appended to decode abbreviations and captions used in this report.

OBJECTIVES

The purpose of Phase III of this investigation was to optimize fabricating processes, alloys and tempers to achieve combinations of properties shown below:

Property	Combination A	Combination B	Combination C
Yield Strength - ksi	95	85	75
K_{Ic} - ksi$\sqrt{in.}$	26	26	45
Exfoliation	High Resistance	Immune	Immune
SCC Threshold Stress - ksi	25	25	42
Fatigue Endurance Limit - ksi			
Notched Axial Stress (K_t = 3, R = 0.0)	14	14	16
Smooth Rotating Beam	22	22	22
Elongation - %	11	11	11

The above targets are averages or typicals for extrusions.

PRODUCTION AND EVALUATION OF ALUMINUM P/M WROUGHT PRODUCTS

I. Extrusions

A. Properties of Extrusions from 170-lb Compacts

1. Material Preparation. Extruded bar in an octagonal section shown in Figure 1 and a 1/2" thick x 6-3/8" wide bar were fabricated for the P/M extrusion evaluation as follows:

Hot pressed compacts were prepared from atomized alloys MA65, MA66, MA83, and MA67 (see Table 5) by the procedure outlined in Table 6 using specific conditions for each compact listed in Table 7. These hot pressed compacts were scalped to 7.25" diameter and cut in two to yield two pieces, each 12.5" long. Billets from the ram end of the hot pressed compact (see Figure 2) were extruded to the 1/2" thick x 6-3/8" wide bar, while billets from the blind die end of the same hot pressed compacts were extruded to the octagonal bar (Figure 1) using extrusion conditions shown in Table 10.

Sections of production D.C. (direct chill) cast 9" diameter 7001 and 7178 and 11" diameter 7075 ingot were scalped to 7.25" diameter and extruded to the octagonal bar and to the 1/2" x 6-3/8" bar along with the P/M billets using extrusion conditions in Table 10.

The extrusion conditions shown in Table 10 revealed lower extrusion breakout pressure for the P/M extrusions when

compared to the same section extruded with I/M (Ingot Metallurgy) 7XXX alloys.

These extrusions were heat treated and aged as shown in Tables 11, 12 and 13. The rate of change of longitudinal yield strength (LYS) with second-step aging time at 325 F was determined from data in Table 11 to provide a basis for estimating the aging conditions necessary to achieve the target yield strengths for the extruded P/M products.

Sections of extruded octagonal bar and 1/2" x 6-3/8" bar were second-step aged as shown in Tables 12 and 13, respectively. The octagonal extrusions were sampled as shown in Figure 1 for tensile and notched tensile properties; stress-corrosion cracking tests of transverse tensile bars exposed in 3.5% NaCl solution by alternate immersion per Federal Test Method 823 (hereafter referred to as "A.I."), and in inland industrial atmosphere at New Kensington, Pennsylvania; and axial stress fatigue tests with stress ratio (R) = 0.0 using smooth specimens and notched (K_t = 3) specimens. The 1/2" x 6-3/8" specimens were sampled as shown in Figure 3 for tensile and Kahn-type tear" tests and for exfoliation panels machined to expose midplane and 10% of thickness planes to the ExCO" accelerated exfoliation corrosion test.[8]

2. Results and Discussion.

a. Tensile Properties. The effect of second-step aging at 325 F on longitudinal tensile properties of octagonal

extrusions is shown in Table 11 and Figure 5. Alloys MA66 and MA67 were capable of higher strength than MA65, but both show a more marked decrease in strength with increasing second-step aging time at 325 F.

Tensile and notched tensile properties of octagonal extruded bar and tensile and tear properties of 1/2" x 6-3/8" extruded bar are shown in Tables 12 and 13, respectively, along with properties of I/M 7001, 7178, and 7075 in these same extruded sections. The P/M extrusions were aged to meet the strength target objectives and to match or exceed the strength of the commercial I/M extrusion alloys.

b. Toughness. The fracture toughness (notched tensile strength/yield strength (NTS/YS) or tear strength/yield strength (TrS/YS)) was a function of yield strength level, as shown in Figures 6-9. Thus, the fracture toughness rating of the various alloy extrusions must be weighted for yield strength.

Relative to the fracture toughness targets stated in the objectives, Targets A and B required a longitudinal NTS/YS of 1.25 to approximate a K_{Ic} of 26 ksi√in., as shown in Figure 10 (from Ref. 5). Alloys MA66 and MA65 met these objectives for Targets A and B (Figure 6), while MA67 achieved the equivalent of a K_{Ic} = 17.5 ksi√in. None of the alloy-tempers tested achieved the fracture toughness equivalent to Target C (K_{Ic} = 45 ksi√in.).

All of the Al-Zn-Mg-Cu alloys (without Co) achieved a somewhat higher longitudinal fracture toughness to YS relationship compared to the 1.6 Co alloy (Figures 6 and 8). The comparison of fine and coarse powders shown in Figures 6 and 8 did not show a conclusive effect of powder size on toughness. This effect will be explored in detail in Section IB2c, page 19. The effect of 1.6% Co in MA67 compared to MA66 clearly decreased the fracture toughness.

In transverse NTS/YS (Figure 6) or transverse TrS/YS (Figure 8), powder size had no apparent effect in these extrusions.

Comparing the P/M extrusions to I/M 7075, 7178, or 7001 showed MA65 and MA66 to have longitudinal NTS/YS equal to the I/M alloys (Figure 7), and MA65, MA66 and MA67 to have longitudinal TrS/YS equal to the I/M alloys (Figure 9). However, in transverse NTS/YS (Figure 7) or long transverse TrS/YS (Figure 9) the I/M extrusions had generally higher fracture toughness, although the toughness advantage of I/M extrusions decreased as yield strength increased. Experiments to improve fracture toughness will be discussed in detail in a following section, along with an experimentally verified procedure to markedly improve fracture toughness.

c. Stress-Corrosion Cracking. The 3.5% NaCl solution alternate immersion SCC test results of transverse tensile bars from octagonal extrusions are shown in Table 14. Performance of the various alloy extrusions was dependent on time

in test, on strength, on aging at 325 F, and on applied stress, as shown in Figures 11 and 12. While 30-day exposure results are frequently used f . specification tests, 84-day exposure results are better indicators of long-time atmospheric SCC performance. Note that even the 84-day test does not always accurately indicate long-time atmospheric exposure results. These later results are required to complete the SCC evaluation.

Relative to the property targets stated in the Objectives, MA67 achieved the SCC objective of Target A (95 ksi LYS, 25 ksi sustained stress), while MA66 achieved the SCC objective of Target B (85 ksi LYS, 25 ksi sustained stress), as shown in Table 14. MA67 would be expected to exceed the Target B SCC objective if aged to 85 ksi LYS. None of the extrusions tested at Target C (LYS of 75 ksi) achieved the SCC objective, including I/M 7075. Fine powder MA65, I/M 7075 and I/M 7178 came closest, sustaining 35 ksi, 35 ksi, and 30 ksi stress, respectively, without failure in the 84-day test (tempers with <70.5 ksi TYS, Figures 12a and b). As shown in Figure 11, these latter three materials passed 30 days in A.I. at up to 45 ksi sustained stress, but did not complete 84 days in A.I. at the higher sustained stresses tested (Table 14).

Relative to the I/M alloys tested, MA67 achieved superior strength at 25 ksi sustained stress, with fine powder MA67 at 85-87 ksi TYS (transverse yield strength) clearly superior to 7001-T6 (Figure 12). MA66 at 74 ksi TYS was superior to 7178-T6

at the same yield strength at 25 ksi sustained stress (Figure 12), with clear superiority after 30 days A.I. (Figure 11) at up to 40 ksi applied stress.

Alloy MA65 extrusions from Phase II aged to meet Targets B or C have not developed SCC failures in New Kensington atmosphere tests (17 months completed in a 48-month test) at 42 ksi stress at 85 or 75 ksi LYS (Table 1, Appendix).

In six months exposure in New Kensington industrial atmosphere SCC tests, no failures have developed in specimens from the Phase III extrusions at sustained stresses up to 45 ksi (Table 2, Appendix). These tests will continue through 4 years exposure.

The beneficial effect of Co_2Al_9 and $FeNiAl_9$ on the stress-corrosion resistance of Al-Zn-Mg-Cu P/M alloys has been known for some time. The reasons for the effect are not yet known. Co_2Al_9 and $FeNiAl_9$ are very similar compounds and the discussion which follows uses the former for illustration.

The compounds appear as small (less than 2 μM) rounded particles as illustrated in Figures 13a and b. The size and spacing of particles in the final wrought product depends on dendrite arm spacing (i.e., solidification rate) in the powder and on fabricating history. The particles are not particularly associated with grain and subgrain boundaries, occurring both at and away from boundaries.

In transmission electron micrographs, Co_2Al_9 appears as dark eliptical particles which are significantly larger than the grain boundary precipitate (M-phase) and the precipitate free zones adjacent to grain boundaries (Figure 14).

This Co_2Al_9 is about 400 millivolts cathodic to the matrix (0.1 N calomel scale). This suggests that when a stress-corrosion crack proceeding along a grain boundary hits a Co_2Al_9 particle, the particle-matrix interface becomes the preferred site for corrosion, with the matrix corroding. Corrosion around the particle could effectively blunt the intergranular corrosion crack tip as shown schematically in Figure 15a, reducing the stress concentration at the crack tip and slowing or stopping the SCC crack. Figures 15b and 15c show metallographic evidence of this stress-corrosion crack blunting at an intermetallic particle in an Al-9.7 Zn-4.1 Mg-0.8 Cu-1.4 Co alloy extrusion transverse tensile bar exposed in New Kensington atmosphere for over four years with 25 ksi sustained stress.[3]

In such a mechanism, the interparticle spacing of Co_2Al_9 along grain boundaries would be an important factor in prolonging SCC failure times, and performance would be enhanced by decreasing spacing. Interparticle spacing decreases with decreasing powder size, and it was observed that fine powder gave better SCC performance than coarse powder (Figure 12c).

Another possible reason for the beneficial effect of Co_2Al_9 is that it may catalyze the reaction of atomic hydrogen formed at the corrosion crack tip to molecular hydrogen and prevent the diffusion of hydrogen along the grain boundary. Direct evidence of this catalysis has been observed in the following experiment. When a massive piece of the Co_2Al_9 compound was embedded in 7075 sheet and the couple was exposed to a heated NaCl solution, it was observed that a gas, presumably hydrogen, was evolved from the interface between the Co_2Al_9 and the 7075.

It was also observed that the Co-free MA66 alloy extrusion exhibited long, straight longitudinal boundaries (Figure 13c) compared to the Co-bearing P/M MA67 alloy (Figure 13b). The increased irregularity of intergranular paths in the Co-bearing MA67 may ennance SCC resistance by increasing the time necessary to corrode to the intergranular stress-corrosion crack-path-length required for specimen fracture.

d. Fatigue. Although it is impossible to reach firm conclusions on fatigue characteristics from the limited data available, results to date are encouraging. All of the P/M alloys tested at 95 ksi and 85 ksi LYS exceeded the axial stress fatigue performance required in the Objectives section for Targets A and B (endurance limit of 14 ksi maximum stress for a K_t = 3 notch and stress ratio (R) = 0.0), as shown in Table 15. Further, P/M MA66 and MA67 at 95 ksi LYS exceeded the notched fatigue per-

formance of the control I/M 7001-T6 at all stresses tested (Figure 16). Near the endurance limit, these P/M alloys exceeded the maximum stress to failure of commercial 7075-T6510 extrusions by 40%.

P/M MA65 at 87 ksi LYS developed slightly superior notched specimen fatigue performance relative to the control I/M 7075-T6 at 87 ksi LYS (Figure 17), with the control 7075-T6 nearly matching the commercial 7075-T6510 fatigue performance.

In axial stress fatigue tests for smooth specimens, at stress ratio (R) = 0.0, P/M MA66 and MA67 at 95 ksi LYS showed superior fatigue life compared to I/M 7001-T6 (Figure 18, Table 16). This superior P/M alloy fatigue performance was evident in spite of the occurrence of fretting-initiated specimen failures in the specimen grips for a large number of the P/M specimens.

Comparing P/M MA65-T6 and the control I/M 7075-T6, both at 87 ksi LYS (Figure 19), the P/M alloy showed superior smooth specimen fatigue performance over the ingot alloy, in spite of the occurrence of fretting-initiated grip failures which tended to shorten specimen life in MA65.

e. <u>Exfoliation</u>. In accelerated ExCO exfoliation corrosion tests, the P/M 1/2" x 6-3/8" extruded bar showed high resistance to this type of corrosion attack regardless of strength. Relative to the target exfoliation corrosion resistance stated in the Objectives, the P/M extrusions readily met the requirements

for high exfoliation resistance, regardless of strength (Figure 20). The vigorous general corrosion attack in the ExCO test precluded determination of immunity to exfoliation corrosion. This determination awaits the exposure of similar test panels in a seacoast environment.

I/M extrusions in the T6 temper developed varying degrees of exfoliation, as shown in Figure 21, with 7001-T6 clearly showing the results of low resistance to exfoliation corrosion (shown as a visible lifting of the surface grains). Further aging at 325 F improved the exfoliation corrosion resistance of 7178 and 7075 at a considerable sacrifice in strength (Figure 20).

In the P/M extrusions, Figure 22 shows that only pitting corrosion resulted from the ExCO exposure, with near-surface samples from fine powder extrusions of MA65 and MA66 being somewhat resistant even to pitting attack. Aging at 325 F did not change the exfoliation corrosion resistance of the P/M extrusions, nor did reducing Fe and Si (Table 17). However, reducing Fe and Si did somewhat reduce the extent of pitting in this test, particularly with samples aged at 325 F.

The high exfoliation resistance of the P/M extrusions can be related to the fragmented (fine powder) or recrystallized (coarse powder) structure of the P/M extrusions (Figures 23a and b, respectively) providing short longitudinal grain boundary segments between intersecting transverse grain boundaries. The

I/M 7075 extrusion (Figure 23c) shows the fibrous elongated structure developed in I/M extrusions that results in underleafing corrosion and lifting of grains because of long continuous path for intergranular corrosion in the longitudinal direction.

3. Conclusions.

a. Alloy MA66 in extrusions achieved the strength, ductility, fracture toughness, resistance to stress-corrosion cracking, and exfoliation resistance required for the Target B combination of properties at 85 ksi LYS.

b. Alloy MA66 met the property combination for Target A (95 ksi LYS) in extrusions except for ductility and resistance to SCC.

c. Alloy MA67 met the property combination for Target A (95 ksi LYS) in extrusions except for ductility and fracture toughness.

B. Alloying and Processing to Improve Fracture Toughness

In analyzing the fracture toughness achieved in Phases I and II of this program,[4,5] it was noted that P/M wrought products were generally no better in longitudinal fracture toughness than I/M 7075-T6, and also were lower than I/M 7075-T6 in transverse fracture toughness. Excessive scatter in the YS vs NTS/YS relationship also obscured expected effects in some cases. Additional studies of factors affecting fracture toughness were, therefore, incorporated in Phase III to improve toughness by:

1. Increasing the amount of hot deformation.

2. Decreasing the amount of constituents.

   a. Decreasing insoluble phases containing Fe and Si.
   b. Eliminating Cu.
   c. Decreasing oxides by using coarser powder.
   d. Decreasing oxides by atomizing with inert gases.
   e. Decreasing oxides by preventing additional oxidation during preheating and transferring of hot compacts from furnace to compacting cylinder.

3. Eliminating entrapped gases by preheating and hot compacting in vacuum.

The results of these studies to improve fracture toughness in P/M extrusions are presented in the above order in the following sections.

1. Increasing the Amount of Hot Deformation. Extruded 7/8" diameter (extrusion ratio = 53:1) and 2" diameter (extrusion ratio = 9.3:1) rod in Al-6.5 Zn-2.2 Mg-1.5 Cu, Al-5.9 Zn-2.1 Mg-2.2 Cu-0.1 Zr and Al-9.2 Zn-2.5 Mg-1.0 Cu alloys were prepared by a procedure outlined in Table 18 from air atomized alloy powders described in Tables 19 and 20. These powders were isostatically cold pressed in a wet bag system at 38 to 40 ksi applied pressure. The green compacts were encapsulated in welded aluminum cans as illustrated in Figure 24a, preheated in flowing argon (CANAR preheat) to 1000 F and soaked at 1000 F for the times shown in Table 21. Immediately after preheating, the compact and can were

hot pressed at 90 ksi and extruded to 7/8" diameter or 2" diameter rod from an extrusion cylinder operated at 700 F at less than 3 feet/minute with extrusion conditions shown in Table 21.

Samples 3/4" diameter machined from 7/8" or 2" diameter extruded rod were solution heat treated, quenched and aged as shown in Tables 22, 23 and 24 for determination of longitudinal tensile and notched tensile properties.

As shown in Table 25, increasing hot reduction in extrusion above an extrusion ratio of 9.3 had no significant effect on longitudinal yield strength, ductility, or fracture toughness (NTS/YS). The effect of hot reduction of less than the equivalent of 9.3 extrusion ratio will be examined further in hand forgings in a later section of this report.

2. Decreasing Amounts of Constituent.

a. Decreasing Insoluble Phases Containing Fe and Si. The extrusions listed in Table 26 were fabricated by the general procedure shown in Table 18 with specific processing conditions shown in Table 26. The effect of the differences in extrusion ratio among these extrusions was considered negligible, on the basis of the results presented earlier (see Table 25). These extrusions were solution heat treated, quenched and aged as shown in Table 27 and tested for tensile and notched tensile properties in the longitudinal and transverse directions.

Reducing the Fe and Si improved the fracture toughness of P/M extrusions at the lower longitudinal and transverse yield strengths (82 ksi and lower) but not at higher yield strengths (92-94 ksi), as seen in Figure 25. It appears that the lower matrix ductility at these high yield strengths may overwhelm the effect of second phase particles on fracture toughness.

b. Eliminating Insoluble and Undissolved Phases Containing Cu. The alloy powders described in Table 28 were fabricated to octagonal extrusions (Figure 1) by the general procedure shown in Table 18 with specific processing conditions shown in Table 29. These extrusions were solution heat treated, quenched and aged as shown in Table 30. Tensile and notched tensile properties of these extrusions were determined, as was stress-corrosion cracking resistance of selected samples.

The fine powder Cu-free Al-Zn-Mg alloys showed an improvement in longitudinal NTS/YS over the Cu-bearing comparison alloys (Figure 26) but little advantage in transverse NTS/YS (Figure 27).

The magnitude of the improvement in longitudinal NTS/YS with eliminating Cu was smaller than the improvement shown in Figure 28 for the effect of decreasing Zn. Since decreasing Zn did not decrease SCC resistance, while decreasing Cu did decrease SCC resistance at high strength (Table 31), eliminating Cu will not be considered further as a means of improving fracture toughness.

c. <u>Decreasing Oxides by Using Coarser Powder</u>. In addition to the extrusions listed in Tables 22, 23, 24 and 30, which include extrusions from fine (15 μM APD) and coarse (48 μM APD) powders, other extrusions of MA65 alloy (Al-6.5 Zn-2.3 Mg-1.5 Cu) from air atomized powders were fabricated to provide a range of processing conditions to detect process and powder size interactions. The alloy/powders described in Table 32 were compacted, preheated and extruded by the general procedure shown in Table 18, with specific conditions for each extrusion as listed in Table 33. In addition to an atmosphere furnace preheat (FCE preheat) with flowing argon, prior to hot working, other compacts were preheated in welded aluminum cans with flowing argon prior to can and compact being hot pressed and extruded (CANAR preheat, Figure 24a). These extrusions were solution heat treated, cold water quenched and aged as shown in Table 34.

Increasing powder size did result in a decrease in the amount of oxygen in the extrusions, but fracture toughness (NTS/YS) decreased with decreasing oxygen (Table 34). Combining these results with those from Table 30, coarser powder (45 μM) did yield lower longitudinal fracture toughness, shown as lower NTS/YS in Figure 29, and substantially lower transverse NTS/YS in Figure 30. The results shown above substantially agreed with the longitudinal fracture toughness for CANAR preheated extrusions shown in Figure 31. The extrusions from coarse powder had lower

longitudinal fracture toughness above 80-85 ksi LYS than fine powder (16 uM) extrusions. In addition, the coarse powder extrusions developed lower transverse fracture toughness at all yield strengths tested.

Examination of the sample having the highest observed density in Table 34, i.e., 0.1020 lb/cu.in., revealed a few scattered fine (<1 uM) pores, Figure 32, indicating that this sample was very near the maximum possible density. Samples having lower density, from coarse powders, contained more and larger pores, and pores were elongated in the direction of metal flow as illustrated in Figure 33.

Particle size analyses (Figure 34) suggest that there are fewer small particles in the coarse powders to fill interstices between larger particles. In addition, it seems reasonable that nonideal packing of particles results in larger interparticle voids in coarse powders than in fine. This would necessitate larger amounts of micrometal flow to achieve complete densification, and for a given amount of macrodeformation, large voids would be more difficult to fill than small ones. Figure 35 illustrates the effect of powder size on pore size in extrusions.

d. Decreasing Oxides by Atomizing With Inert Gases. Powders of Al-6.5 Zn-2.3 Mg-1.5 Cu alloy were prepared by inert gas aspirating and air collecting to generate alloy extrusions from powders with reduced amounts of oxide. The alloy compositions

listed in Table 35 were atomized with air, nitrogen, argon or helium to yield fine and coarse powders of powder sizes shown in Table 36. Inert atomizing did result in a substantial reduction in the amount of oxygen in the powder as shown in Table 35 comparing argon and air atomized powders of near equal powder size. This reduction in oxygen may be partially related to: (a) decreased surface area of the smooth, regular shaped particles of the argon atomized powders (Figure 36a) compared to the irregular shaped air atomized particles (Figure 36b) and (b) decreased amount of fine particles in the regular, inert atomized powders (Figure 34) compared to the irregular, air atomized powders. No measurements of oxide thickness were made to determine that contribution to reducing the amount of oxide.

These alloy powders were compacted, preheated and extruded by the general procedure shown in Table 18, with specific conditions for each extrusion listed in Table 37. The bulk of these samples were CANAR preheated (can preheat/hot press with argon) as shown in Figure 24a, while selected samples of air and argon atomized powders were FCE preheated.

The extrusions listed in Table 38 were solution heat treated, cold water quenched and aged as shown for determination of longitudinal and transverse tensile and notched tensile properties.

Inert atomizing variations used to prepare Al-6.5 Zn-2.5 Mg-1.5 Cu extrusions resulted in variations in the amount of oxide in the extrusions and variations in the ductility and fracture toughness (Table 38). Among the inert atomizing gases, argon generally gave superior transverse ductility and comparable NTS/YS to the materials prepared with helium or nitrogen. Because all of the inert gases gave smooth, regular shaped powder, as illustrated in Figure 36a, the extrusions from argon-atomized powders were selected for detailed study as being representative of regular shaped, inert atomized alloys. These were compared to extrusions from air atomized powders.

Because this study was intended to improve toughness by decreasing the amount of oxide second phase particles, it was of interest that mechanical properties, particularly transverse elongation, NTS/YS and tensile strength were found to increase with increasing oxygen content (Figure 37). One reason for the contrary trend was porosity, as illustrated by density differences between extrusions from regular (argon atomized) and irregular (air atomized) powders (Table 39). These density differences had a most potent effect on transverse mechanical properties, particularly NTS/YS near the highest observed density (Figure 38).

A reason for the inferior properties with regular shaped, inert atomized powders is suggested by the way these particles might pack during densification. Irregular-shaped particles give

rise to long thin voids between particles which close readily with applied hydrostatic stress and are sheared readily during extrusion. Additionally, metal tails and particle surface projections provide metal to fill small voids at particle interstices by combined hydrostatic stress and shearing metal flow in extrusion. Relatively smooth, regular particles result in regular, near spherical voids at particle interstices which will not fully close with applied hydrostatic stress. Further, these small, numerous, near spherical voids are resistant to closing in combined hydrostatic stress and shearing metal flow in extrusion.[10]

Powder shape had a more significant effect on fine powders than on coarse, with regular particles giving 0.5% lower density but up to 28% lower transverse fracture toughness (NTS/YS) than irregular particles (Table 39).

e. Decreasing Oxides by Preventing Additional Oxidation. In inert-gas atmosphere-furnace preheating (FCE preheat), some dilution of the inert gas by air takes place when opening the furnace to remove a compact (Ref. 4, Table 5), exposing the remaining compacts in the furnace to oxygen. In addition, transporting the compact in air to a press for hot working would be expected to further expose the compact to oxygen. Preheating the compact in flowing argon inside a welded aluminum can and hot pressing the compact in the can (CANAR preheat) eliminates both of these sources of oxidation and would be expected to result in

lower amounts of oxides than atmosphere furnace preheating. The extrusions from air and argon atomized powders listed in Table 38 processed with FCE and CANAR preheat did show reduced oxygen with CANAR preheat (Table 40). However, this reduced oxygen was accompanied by reduced density and reduced fracture toughness in both longitudinal and transverse directions (Table 40). CANAR preheat generally shows reduced fracture toughness even after compensating for differences in yield strengths (Figures 39 and 40).

One possible explanation for the superiority of FCE preheating over CANAR preheating lies in gas entrapped in the can in hot pressing interfering with interparticle bonding. Processing a bare compact allows egress of interparticle gas which passes the compacting cylinder dies to escape the compacting cylinder, thus allowing intimate contact and bonding between particles. Since a nonreactive gas (e.g., argon) in a pore impedes pore closing during hot pressing and extruding, lower density might be expected in CANAR preheating if argon is trapped in the can. Evidence of this was higher density in FCE preheat extrusions compared to CANAR preheat extrusions (Table 40).

3. <u>Eliminating Entrapped Gases by Vacuum Preheating and Hot Compacting</u>. The above evidence of gas entrapment in CANAR preheat compared to FCE preheat led to the trial of a vacuum preheat/hot press, i.e., preheating with a vacuum and maintaining

the vacuum in hot pressing by weld-sealing the evacuation line prior to hot pressing (VAC preheat, Figure 24b). Alloy powders described in Table 41, prepared by air and nitrogen atomizing, were processed by the general procedure outlined in Table 18, using specific processing conditions shown in Table 42, to the 1-9/16" octagonal extruded bar shown in Figure 1. In addition to VAC preheating, compacts were (a) preheated in cans with flowing nitrogen and hot pressed in the can (CANIT preheat, Figure 24a) or (b) preheated in retorts with flowing nitrogen and hot pressed bare in an extrusion cylinder (RET preheat, Figure 24c) prior to extruding. Some samples being vacuum preheated developed air leaks of varying degrees during sealing (AVAC preheat).

These octagonal extrusions were solution heat treated, cold-water quenched and aged as shown in Table 43 for determination of longitudinal and transverse tensile and notched tensile properties. Selected samples listed in Table 44 (those achieving the highest transverse NTS/YS) were also sampled for plane-strain fracture toughness (K_{IC}) specimens.

VAC preheat/hot press of MA83 alloy clearly gave very dramatically improved fracture toughness over inert gas preheat/ hot press (Table 43), particularly in the transverse direction. The improvement in transverse toughness was well beyond any of the individual incremental improvements observed for the individual factors discussed earlier (Figure 41).

The toughness improvement with VAC preheat was not entirely explained by differences in density as shown in Figure 42. CANIT and RET preheated extrusions showed improved NTS/YS with increasing density, while vacuum preheating and hot pressing gave substantially higher NTS/YS than any gas preheated extrusions at the same density. As observed earlier (Figure 38), ductility improved at near maximum density regardless of preheat.

A substantial part of the toughness improvement with VAC preheat was related to minimizing gas content in preheat/hot pressing (Figure 43, Table 45) to avoid entrapped gas interfering with interparticle bonding. In addition to eliminating interference of gas with bonding, increasing the hot compacting pressure to increase bonding force gave improved transverse fracture toughness (Figure 44) for both vacuum and inert gas preheats.

A part of the improvement in fracture toughness with vacuum preheat may be the result of diminishing the amount of second phase in the extruded structure compared to nitrogen preheat as shown in Figure 45. The white constituent in Figures 45c and 45d appears to be an oxide (generated in decomposition of water adsorbed on the powder particle surfaces during heat up) or a nitride (generated by reaction of aluminum and nitrogen during preheating).

P/M MA83 extrusions with VAC preheat compared favorably with experimentally generated I/M 7050 and 7075 extrusions (in Table 45), with the VAC preheated MA83 surpassing both 7050 and 7075 in transverse plane-strain fracture toughness (K_{IC}) and ductility. When properly processed, the P/M alloy appeared to show somewhat less anisotropy in ductility and fracture toughness (K_{IC}) than 7050 and 7075, possibly due to the fine grain size and constituent size.

4. Conclusions.

a. Vacuum preheat/hot press substantially improved the longitudinal and transverse fracture toughness of P/M extrusions.

b. Vacuum preheated MA83 extrusions surpassed the transverse plane-strain fracture toughness and ductility of 7050 and 7075 extrusions.

The following conclusions are tentative because they are based on inert gas preheated material and are clouded by unknown amounts of gas and porosity:

c. Fine powder (16 μM APD) of irregular shape (as atomized in air) provided maximum extrusion density and transverse ductility and fracture-toughness (NTS/YS) in extrusions from inert gas preheated compacts.

d. Among inert gas preheats, maximum transverse toughness (NTS/YS) was achieved by furnace or retort preheating followed by bare compact hot pressing preceding hot working.

e. Reduced Fe and Si improved fracture toughness below 85 ksi YS in both longitudinal and transverse directions.

f. Eliminating Cu in Al-9 Zn-2.5 Mg alloys improved fracture toughness in extrusions in longitudinal direction.

g. Reducing Zn improved fracture toughness in longitudinal and transverse directions.

C. Quench Sensitivity

The preparation and heat treatment of the Al-Zn-Mg and Al-Zn-Mg-Co extrusions listed in Table 30 was described above in section IB2b, page 18, under programs to improve fracture toughness. These extrusions were also used to study quench sensitivity by varying the quench rate after solution heat treatment.

As shown in Table 46, the extrusions made from coarse powder were substantially less quench sensitive than those from fine powder. In the absence of Co, Cu slightly decreased quench sensitivity. In the absence of Cu, Co slightly increased quench sensitivity. Combined Co and Cu additions increased quench sensitivity.

II. Die Forgings

A. Properties of Die Forgings from 170-lb Compacts

1. Material Preparation. The die forging shown in Figure 46, designated Die 9078, was fabricated from P/M 4" diameter extruded rod as follows.

Hot pressed compacts of alloys MA65, MA66, MA83, and MA67 (listed in Table 5) were prepared by the procedure outlined in Table 6 using specific conditions for each compact listed in Table 47. These hot-pressed compacts were scalped to remove 1/8"-1/4" off the diameter, reheated and extruded to 4" diameter rod using extrusion conditions listed in Table 48.

The die forging was prepared in a two-step block and finish sequence. The 4" diameter rod was reheated to 800 F and forged in a blocker die heated to 800 F. After trimming excess parting plane flash, the blocker forging was reheated to 800 F and finish forged in 800 F dies. The relative scale of the green compact, hot pressed compact, extruded 4" diameter rod and the 9078 die forging is shown in Figure 46. I/M alloy 7075 forgings were similarly fabricated, starting with 11" diameter D.C. ingot, scalped to 9" diameter to provide a comparison commercial alloy product.

The forgings were solution heat treated at 920 F (P/M alloys) or 880 F (7075) for 2 hours, quenched as shown in Table 49, aged 6-7 days at room temperature plus 24 hours at 250 F. Selected forgings were further aged 6 hours at 325 F, as shown in Table 49.

These forgings were sampled as shown in Figure 47 for web and flange tensile and notched tensile properties and for SCC test tensile bars across the parting plane for accelerated A.I. (alternate immersion per Federal Test Method 823) and industrial atmospheric (New Kensington, Pa.) exposures.

2. Results and Discussion. The mechanical properties of the 9078 die forgings are summarized in Table 49, while the A.I. SCC performance is shown in Table 50. Table 3, Appendix, shows the progress of New Kensington atmosphere SCC tests to date, with 170-230 days completed in a planned 4-year test.

The P/M forgings clearly achieved superior strength compared to I/M 7075 alloy as shown in Table 49. However, all of the P/M alloys were inferior in fracture toughness (NTS/YS) compared to I/M 7075, particularly in the short transverse direction (across the parting plane) as shown in Figure 48. The processing for these forgings included an argon preheat in an atmosphere furnace and argon/air hot press; it is anticipated that vacuum preheat/hot press processing will substantially improve fracture toughness in all directions, particularly in the transverse direction as was accomplished in extrusions (see Figure 41).

Stress-corrosion performance in alternate immersion is shown as a function of STYS in Figures 49 and 50. The SCC performance is in terms of percent surviving after 30 days and 84 days at stresses of 25, 30, 35, 40, and 45 ksi. The I/M 7075-T6

control which was carried in this experiment is shown as are curves for I/M 7049 and I/M 7050 die forgings (die 9078 and similar forgings) from other investigations.[11]

After 30 days, MA67 was capable of higher strengths for a given level of SCC resistance than the other P/M and I/M materials shown in Figure 49. MA66 alloy appeared to be inferior to MA67 in the combination of strength and resistance to stress-corrosion cracking but was superior to 7075, 7050 and 7049 at lower levels of applied stress. MA65 alloy was superior to I/M 7075 but inferior to the other P/M alloys and to 7049 and 7050 die forgings.

After 84 days, MA67 was capable of higher strengths at a given level of SCC resistance than the other P/M and I/M materials in Figure 50. MA66 appeared to be inferior to MA67, about the same as 7049 and 7050, and superior to 7075. MA65 was superior to 7075 but inferior to 7049 and 7050.

In the absence of a correlation between A.I. and long-time exposure in natural environments for these new alloys, the relative ranking of the SCC properties of these materials is considered tentative. Long-time tests in New Kensington atmosphere are in progress.

3. Conclusions.

a. MA67 alloy developed a better combination of strength and resistance to stress-corrosion cracking in die forgings than I/M 7075, 7049 and 7050 in accelerated tests.

b. P/M alloys MA65, MA66 and MA67 all developed better combinations of strength and resistance to stress-corrosion cracking than I/M 7075 forgings.

c. P/M alloy die forgings fabricated from inert gas preheated compacts had lower fracture toughness than I/M 7075 forgings.

III. Hand Forgings

A. Properties of Hand Forgings from 170-lb Compacts

1. Material Preparation. Hand forgings 2" thick x 10" wide x 47" long were fabricated from atomized alloys as follows.

Hot pressed compacts (see Figure 2) of alloys MA65, MA66, and MA67 (listed in Table 5) from 15 μM and 50 μM (APD) powders were fabricated by the procedure outlined in Table 6, using specific conditions for each compact listed in Table 51. These hot pressed compacts were scalped to 7.5" diameter x 22.5" long, reheated to 700 F and forged by an "A" upset and draw procedure (as shown in Figure 51) to 2.2" x 10" x 47". A billet 7.5" diameter x 22.5" long from 11" diameter 7075 D.C. ingot was similarly forged to provide a comparison material for testing. After ultrasonic inspection, the forgings were scalped to 2.05" thick (removing equal amounts from each side of forging) to provide a uniform quenching thickness and parallel sides for compressive stress relief.

The forgings were solution heat treated at 920 F (P/M alloys) or 880 F (I/M 7075), quenched and aged as shown in Table 52. These forgings were sampled for tensile and notched tensile properties in the longitudinal, long transverse and short transverse directions and for short transverse tensile bars for accelerated A.I. and atmospheric (New Kensington, Pa.) SCC tests, as shown in Figure 52.

2. Results and Discussion. The mechanical properties of the 2" thick hand forgings are summarized in Table 52, while A.I. SCC performance is presented in Table 53. Table 4, Appendix shows the samples in New Kensington atmosphere, with 170-270 days completed in planned 4-years test.

The quench sensitivity exhibited by these P/M alloy forgings appeared to be substantially less than 7075,[13] comparable to 7049,[14] and slightly higher than 7050,[15] based on the effect of decreasing quench rate on longitudinal yield strength shown in Figure 53.

Second-step aging at 325 F decreased the longitudinal yield strength as shown in Table 54 and Figure 54. MA65 alloy, with higher Cu and lower Zn + Mg, lost strength slower than either MA66 or MA67.

The coarse powder hand forgings compared rather favorably in longitudinal and long transverse ductility and fracture toughness with the fine powder forgings, as shown in Table 52 and Figure 55a and b. However, the poor short transverse (ST) ductility and very poor STYS and NTS/YS of the coarse powder hand forgings (Table 52) eliminated these materials from further serious study.

The fine powder hand forgings clearly achieved superior strength relative to I/M 7075 in all directions. However, the fine powder forgings were inferior in fracture toughness (NTS/YS) compared to I/M 7075 in the longitudinal and long transverse

directions (Figure 55). The processing for these forgings included an argon preheat in an atmosphere furnace and argon/air hot press; it is anticipated that vacuum preheat/hot press processing will substantially improve fracture toughness in all directions, particularly in the transverse direction as was accomplished in extrusions (see Figure 41).

After 30-day exposure in A.I. stress-corrosion testing, all of the P/M alloy hand forgings developed superior strength and SCC resistance compared to I/M 7075, as shown in Figure 56. In order of increasing strength with SCC resistance, the P/M alloys would rank in the following order: MA65, MA66, and MA67.

After 84-day exposure in A.I., none of the P/M alloy-tempers passed at 30 ksi ST sustained stress (Figure 57). MA65 at 62 ksi STYS and MA67 at 69 ksi STYS sustained 25 ksi stress without failure. MA66 and the other P/M alloys would be expected to sustain higher stress without failure at lower yield strengths than those tested here.

The superior strength and stress-corrosion cracking resistance of the P/M forgings compared to I/M 7075 appears to be related to the very fine grain size of the P/M forgings in all directions (illustrated for MA65 in Figure 58), and to the combination of fine grain size and fine distribution of Co_2Al_9 achieved in P/M alloys with cobalt, illustrated in Figure 59. Note that the Co_2Al_9 particles are not appreciably elongated by

working in hand forging, and that the grains are more equiaxed in MA67 than in MA65.

3. Conclusions.

a. P/M MA65, MA66 and MA67 alloy hand forgings developed superior strength with SCC resistance compared to I/M 7075 hand forgings.

b. P/M alloy hand forgings fabricated from argon preheated hot pressed compacts had inferior fracture toughness compared to I/M 7075.

B. Optimization of Processing for Forgeability

1. Material Preparation. Three kinds of hand forgings were made and evaluated to determine the effect of process variables on quality as noted by visual examination and ultrasonic inspection. The kinds of forgings were:

a. 5" square stepped to 3" square.

b. 5" square stepped to 3.5" square stepped to 2" square.

c. 5" x 10" x 36".

The process variables were alloy, powder size, preheat atmosphere, temperature and time, hot compacting pressure, amount of scalp, and amount of hot work.

Hot pressed compacts (see Figure 2) of alloys MA65, MA66, and MA67 were fabricated by the procedure outlined in Table 6 using specific conditions for each compact as listed in Table 55. The

hot pressed compacts were scalped as shown in Table 55, reheated to 700 F and forged by an "A" upset and draw procedure as shown in Figures 51, 60, and 61.

The forgings were etched and visually inspected for cracking on the faces and unrestrained ends. Prior to ultrasonic inspection, the 3" square and 5" square forgings were solution heat treated for 2 hours at 920 F, cold water quenched, and aged 4-7 days at room temperature plus 24 hours at 250 F. The other forgings were ultrasonically inspected in the as-forged temper. The ultrasonic inspection used a 10 MHz, 3/4" diameter lithium sulfate search unit and standardization for a 2" trace-to-peak indication from the 3-0075 (No. 3) Reference Block (3/64" diameter flat bottomed hole). The volume of metal meeting SNT Class "A" Standards was computed and recorded as "per cent metal recovery" in Table 56. The 2" x 10" x 47" hand forgings described earlier (Section IIIA, page 33) were also inspected for forgeability in the following discussion.

2. Results and Discussion. The quality ratings of the P/M hand forgings described above are summarized in Table 56 and discussed by process step below.

a. Effect of Alloy. Alloys with low insolubles (i.e., no cobalt) yielded slightly better recovery than the alloy with 1.6 Co (Table 57), particularly at high hot compacting pressure (90 ksi) for fine powder (15 μM APD).

b. Effect of Powder Size. Decreasing powder size substantially improved forging quality, as shown in Tables 57, 58, and 59, for all compacts fabricated to square or rectangular hand forgings. Forgings from 50 μM (APD) powders gave unacceptable forging quality, with some compacts cracking during loading for hot pressing and the hot pressed billets cracking severely during forging. Forgings from 23 uM powders were marginally acceptable. Only the forgings from 15 μM powders were nearly perfect (Table 57), notably at high hot compacting pressures.

c. Effect of Preheat Atmosphere. Preheating in a retort with any of the atmospheres shown in Table 60 resulted in high metal recovery. Inert gas preheating resulted in forgings with generally fewer cracks than with ambient air preheating in a retort, although the cracks in the latter forging were quite shallow. Furnace air preheating (in a circulating air reheat furnace) resulted in severely cracked forgings and very little sound metal.

Changing the gas flow rate had very little effect on forging quality for either argon or nitrogen preheating (Table 60). Changing the inert gas from nitrogen to argon had no significant effect on forging quality (Table 61). Nitrogen preheating gave forgings with less surface checking than argon. This checking was only a surface condition.

d. Effect of Preheat Temperature. No appreciable changes in forging recovery resulted from the preheat temperature variations shown in Table 61. It is significant to note that a compact preheated at 1050 F (70 F above the solidus) cracked in handling before hot pressing. Temperatures substantially above the alloy solidus temperature may be excessive for routine preheating of large compacts.

e. Effect of Preheat Time. Increasing preheat time from 1 to 5 hours improved recovery slightly with little effect on the amount of cracking during forging (Table 60).

f. Effect of Hot Compacting Pressure. Decreasing hot compacting pressure from 90 ksi to 75 ksi resulted in small improvement in metal recovery and visual quality (Table 57, forgings from 23 μM powders) but with a substantial increase in the number of small isolated discontinuities in the forgings (Table 62). This trend was observed previously (Ref. 4, pg. 70). Further decreasing the hot compacting pressure from 75 ksi to 60 ksi did not appreciably change the amount of sound forging but did slightly decrease visual quality with increased surface checking.

g. Effect of Amount of Scalp. Some scalping to remove the oxidized and contaminated metal at the hot compact surface is necessary to produce flaw-free forgings. As shown in Tables 63 and 64, the unscalped billets gave forgings with less than 50% of its volume as sound forging, with severe cracking

extending well into the forging. A small scalping cut, on the order of 0.3" off the diameter and the ram end, appears necessary to remove the contaminated surface (Table 63). Part of the loss of sound material from the 5" x 10" x 36" hand forgings from unscalped compacts (Table 64) was the result of buckling in upsetting due to excessive length/diameter ratio, resulting in an extensive fold at one end of the forged slab.

More extensive cracking in pieces with slight blind die end scalp suggests that the blind die end of the compact is less forgeable than the ram end (Table 63). This may be due to a pressure gradient in hot pressing, with pressure decreasing with distance from the ram dummy block. This effect is probably related to hot compact length to ram end diameter ratio, in this case 3.3:1.

h. Effect of the Amount of Hot Work. Increasing amounts of hot work in forging did not appreciably affect forging quality (Table 65), but affected mechanical properties, to be discussed in a following section.

3. Conclusions.

a. Compacts from fine powders (15 μM APD) had superior forgeability compared to compacts from coarser powders (22 to 50 μM APD).

b. Preheating in nitrogen, argon or in a closed retort gave better forgeability than circulating air furnace preheating.

c. Scalping of hot pressed compacts is necessary prior to forging to minimize cracking during hot forging.

d. Reducing hot compacting pressure below 90 ksi increased the number of isolated discontinuities in hand forgings without appreciably affecting forging recovery.

e. The following process variations had no appreciable effects on forging quality:

Preheat temperatures from 950 to 1050 F.
Preheat times from 1 to 5 hours.
Increasing hot reductions from 75 to 95%.

C. Effect of Process Variations on Fracture Toughness and Ductility of Hand Forgings

1. Material Preparation. The fabrication of P/M 3" square and 5" square hand forgings was described in Section IIIB, page 36. These hand forgings were heat treated and tested for mechanical properties as shown in Table 66, and sampled as shown in Figure 60. The forging with 75 to 97% reduction (404877H1) was sampled as in Figure 61 for 1" blanks, which were heat treated and aged as shown in Table 67. These properties are discussed below.

2. Results and Discussion.

a. Effects of Alloys. Increasing Zn+Mg+Cu increased strength and decreased ductility and fracture toughness (NTS/YS) in all test directions. The 1.6% Co in MA67 increased the strength slightly over MA66, notably in the transverse directions in 3"

square hand forgings, but generally reduced ductility and fracture toughness (see Table 68).

b. Effect of Powder Size. Increasing powder size resulted in increased strength and generally decreased ductility and fracture toughness (NTS/YS), as shown in Table 68. As pointed out previously (Table 57), increasing powder size substantially decreased forging quality due to cracking during forging, yielding forgings of less than ultrasonic SNT Class "A" quality.

c. Effect of Preheat Atmosphere. While strength was not appreciably affected by changing preheat atmosphere (Table 66), fracture toughness (NTS/YS) and ductility did vary with changing atmosphere. Longidutinal NTS/YS and ductility were highest for argon preheating at any of the flow rates shown in Tables 69, 70, and 71, with nitrogen preheating only slightly inferior to argon.

Fracture toughness in the two transverse directions showed nitrogen to be superior to argon, substantially so at high gas flow rates (Table 69). Increasing gas flow rate decreased toughness with argon, but increased toughness for nitrogen. Highest transverse toughness was achieved with 0.75 CFH/lb flow rate for nitrogen preheat. Transverse ductility showed no consistent effect of changing preheat gas (Tables 70 and 71).

It was suggested that the poor toughness with argon preheating might result from argon entrapment in hot pressing.

The preheat gas should displace the gas evolving from the powder surface in the interstices of the compact during preheating. This preheat gas then would occupy the pores in the compact and might interfere with densifying once the interconnected porosity was closed during hot pressing. With nitrogen in the compact's interstices, a potential reaction with aluminum could eliminate the gas in pores (by converting to solid AlN), allowing more complete densification.

Analyses confirmed the presence of argon in the forging preheated in that gas and the absence of argon in the forging preheated in nitrogen. Furthermore, the nitrogen-preheated forging contained more total nitrogen than the argon-preheated forging. The most significant result, however, was that 98-99% of the gas in both forgings was hydrogen (Table 72) and that low short transverse toughness was associated with a high gas content (Table 73). Although densities were equal within experimental error, careful examination with scanning electron microscope confirmed the presence of more porosity in the forging having lower transverse toughness and higher gas content (Figure 62).

It is not clear why this particular set of preheating conditions gave lower gas content. In any case, vacuum preheating and hot pressing has substantially improved toughness, especially in the transverse direction (Figure 41).

Preheating in a retort with no gas flow gave substantially lower ductility and fracture toughness in all test directions. Poor fracture toughness in this material (Table 69), even in the longitudinal direction, precludes further consideration of this preheat method.

Atmosphere furnace preheating with argon gave lower transverse fracture toughness (Table 69) and short transverse ductility (Tables 70 and 71) than retort preheating. One possible explanation might be in re-gassing of the compact preheated in the atmosphere furnace due to atmosphere dilution with moist air in the furnace when the furnace door is opened,[4] and due to exposure to moist air in transporting the compact from furnace to compacting cylinder (3 to 5 minutes in air). The effect of high gas content in reducing toughness was discussed earlier.

The evidence that re-gassing is occurring was the oxidation of the compact, presumably from air penetration into the compact, shown in Figure 63 and Table 74. This re-gassing could affect properties in up to 84% of the volume of the forging, with the "A" upset and draw forging (Figure 51) serving to spread the affected region along the entire length of the forging.

Using retorts or cans for individual compact preheating is preferred to atmosphere furnace preheating to avoid air contamination and reduced fracture toughness. Vacuum preheating and hot pressing, to eliminate exposure to air, has given improved fracture toughness (Figure 41).

d. Effect of Preheat Temperature. Increasing preheat temperature from 950 to 1000 F improved transverse ductility and fracture toughness with no effect on longitudinal properties (Table 75). Further increasing temperature to 1050 F generally decreased transverse NTS/YS and ductility.

e. Effect of Preheat Time. Increasing preheat time from one to five hours had no appreciable effect on fracture toughness or ductility of hand forgings (Tables 69, 70, and 71).

f. Effect of Hot Compacting Pressure. Increasing hot compacting pressure from 60 ksi to 90 ksi had little effect on mechanical properties, as shown in Table 76. The slightly higher average yield strength for the forgings hot pressed at 90 ksi was balanced by a corresponding decrease in fracture toughness (NTS/YS). Part of the decline in NTS/YS with increasing hot compacting pressure was the result of an incidental increase in exposure to argon diluted with air. As shown in Table 77, the experiment had an accidental bias which had number of door openings (during which the argon atmosphere was diluted by air) increasing with increasing hot compacting pressure. This may have resulted in gas readsorption in the compact and a consequent decline in fracture toughness. As shown in Table 77, this increased exposure to air did not oxidize the compact.

As discussed earlier (Section IIIB, 2f, page 39), decreasing hot compacting pressure below 90 ksi severely affected

quality of hand forgings, making 90 ksi a minimum hot compacting pressure for compacts to be hand forged.

g. Effect of Amount of Hot Work. Increasing hot work resulted in a marked increase in transverse fracture toughness (NTS/YS) with little effect on other mechanical properties (Table 67, Figure 64). Based on Figure 64, it is desirable to use L = 20 (reductions of 95%) or greater for optimizing transverse fracture toughness. The improved fracture toughness appears to be partially the result of decreased porosity with increasing reduction (Figure 65).

3. Conclusions.

a. Increasing alloying additions increased strength but decreased ductility and fracture toughness.

b. Increasing powder size increased strength but markedly decreased ductility and fracture toughness.

c. Nitrogen gas preheating gave forgings with superior transverse fracture toughness in hand forgings over forgings prepared with argon preheating.

d. Preheating in a retort followed by bare compact hot pressing resulted in forgings with superior transverse fracture toughness compared to forgings from atmosphere furnace preheated compacts.

e. Increasing amounts of hot work substantially improved transverse fracture toughness in hand forgings, notably from 75 to 90% reduction.

f. Preheating at 1000 F gave superior fracture toughness compared to 950 or 1050 F preheat temperatures.

g. Increasing preheat time from 1 to 5 hours or increasing hot compacting pressure from 60 to 90 ksi did not affect mechanical properties.

IV. Plate

A. Properties of 1.5" Thick Plate from 170-lb Compacts

1. Material Preparation. Hot rolled P/M 1.5" thick plate was fabricated for evaluation by the following procedure.

Hot pressed compacts of MA65, MA66, and MA67 atomized alloys were prepared by a procedure outlined in Table 6 using specific processing conditions for each compact as listed in Table 78. These hot pressed compacts were reheated and forged by the "A" upset and draw sequence shown in Figure 51 to 5" thick x 10" wide x 36" long slabs. These slabs were scalped as shown in Table 79 to approximately 3-1/4" x 8-1/2" x 31", reheated to 700 F and hot rolled to 1.5" thick. This plate was solution heat treated 2 hours at 920 F, cold water quenched, stretched and aged as shown in Table 80. The plate was sampled for properties as shown in Figure 66 in the three principal directions, notched tensile strength in L and LT directions and ST direction tensile bar SCC performance in the accelerated A.I. test per Federal Test Method 823 and in New Kensington, Pennsylvania, atmosphere.

2. Results and Discussion. The mechanical properties of the 1-1/2" thick P/M plate are summarized in Table 80, while the A.I. SCC performance is shown in Table 81. Table 5, Appendix shows the progress of New Kensington atmospheric SCC tests to date, with up to 258 days completed in test in a planned 4-year test.

The P/M plate clearly achieved superior strength compared to I/M 7075 and 7050 alloy plate, as shown in Figure 67.

However, the P/M alloy plate was inferior in fracture toughness (NTS/YS). The processing for this plate included an argon preheat in an atmosphere furnace followed by argon/air hot press; it is anticipated that vacuum preheat/hot press compacting will substantially improve fracture toughness in all directions, as demonstrated in extrusions earlier (Figure 41).

After 30 days in A.I. (Figure 68), all materials tested were superior to I/M 7075 in the combination of strength and resistance to SCC. MA67 was the best of the materials tested. MA66 was superior to I/M 7050 and to MA65. MA65 appeared fairly similar to I/M 7050.

After 84 days in A.I. (Figure 69), test conditions did not permit a conclusion on the relative merits of the materials at stresses of 35 ksi and higher. At 25 and 30 ksi, MA67 was superior to I/M 7075 and I/M 7050.

As shown in Table 5, Appendix, the P/M and I/M alloys in single-step aged tempers and X7050-T6X1 developed SCC early in the planned 4-year test, as was the case in the 84 day A.I. test results shown in Table 81.

3. Conclusions.

a. MA67 alloy developed a superior combination of strength and resistance to SCC in plate over I/M 7050 and 7075 alloys as well as the other P/M alloys in accelerated tests.

b. P/M alloys MA65, MA66 and MA67 all developed superior combinations of strength and resistance to SCC after 30 days A.I. exposure compared to I/M 7075.

c. P/M plate fabricated from inert gas preheated compacts had inferior fracture toughness compared to I/M 7075 and 7050 plate.

V. Sheet

A. Properties of 0.090" Thick Sheet from 170-lb Compacts

1. Material Preparation. P/M 0.090" sheet was fabricated for evaluation by the following procedure.

Hot pressed compacts of MA65, MA66 and MA67 atomized alloys (Table 5) were prepared by a procedure outlined in Table 6 using specific processing conditions for each compact as listed in Table 82. These hot pressed compacts were reheated and forged by an "A" upset and draw sequence shown in Figure 51 to 5" thick x 10" wide x 36" long slabs. These slabs were scalped as shown in Table 83 to approximately 2" x 7-1/2" x 24", reheated to 700 F, hot cross rolled to 9" wide and hot longitudinally rolled to 0.250" thick. A section of this 0.250" plate was reheated to 700 F and hot rolled in one pass to 0.144" thick. This sheet was annealed 2 hours at 650 F and cold rolled to 0.090" thick.

The samples listed in Table 84 were solution heat treated 1 hour at 920 F, cold water quenched, stretched 1.8%, aged 5 days at room temperature plus 24 hours at 250 F. These materials were sampled for longitudinal and transverse tensile and Kahn-Type tear tests[7] and for exfoliation corrosion with machined surfaces exposing planes 10% below rolled surface and mid-thickness to the ExCo test.[8] The effect of second-step aging at 325 F on longitudinal tensile properties was determined on samples listed in Table 85.

The effect of annealing temperature on grain size in the 0.090" sheet wa determined to be as shown in Table 86. Since 920 F, the solution heat treatment temperature, gave the finest or near the finest grain size, no separate annealing treatments prior to SHT were used on material to be tested in a heat treated and aged condition.

Properties of annealed material listed in Table 87 were determined on sheet samples annealed for one hour at 920 F, rapidly cooled to 750 F, cooled at 50 F/hour to 450 F, held 4 hours at 450 F and air cooled to room temperature. Tensile properties in the longitudinal, transverse and at 45° to the longitudinal direction were determined, as were the Strain Hardening Coefficient[17] (η in $\sigma = \epsilon^{\eta}$) and the Strain Ratio[18] ($R = \frac{\text{width strain}}{\text{thickness strain}}$) in the three directions on this annealed material.

2. Results and Discussion. The mechanical properties of the heat treated and aged tempers of the P/M 0.090" sheet are presented in Tables 84 and 85, while the tensile properties of the annealed sheet are shown in Table 87, and the strain hardening coefficients and strain ratios in Table 88. ExCO exfoliation corrosion test results are summarized in Table 89.

While P/M alloys MA66 and MA67 achieved higher strength than I/M 7050, the latter showed superior fracture toughness (TrS/YS or U.P.E. in Table 84). MA65 alloy showed equal strength

and fracture toughness compared to 7075. MA66 alloy achieved better longitudinal strength than I/M 7050, but only matches I/M 7050 strength in the transverse direction. All of the P/M alloys showed inferior strength and fracture toughness (TrS/YS) compared to I/M 7050 (Figure 70). However, this P/M sheet was fabricated from inert gas preheated compacts. On the basis of the effect of vacuum preheat/hot press on the fracture toughness of extrusions (Figure 41), it is anticipated that incorporating this preheat in compacts for sheet will substantially enhance fracture toughness.

The annealed P/M sheet in all alloys showed strengths below the typical strength for 7075-0 and ductility above typical 7075-0 elongation (Table 87).

The strain hardening coefficient and strain ratio provide qualitative ratings of the relative formability of sheet materials. The values of η and R shown in Table 88 for the P/M alloys are generally typical of aluminum base alloys, although the coarse powder (50 μM APD) sheet in MA65 and MA66 alloys clearly show high η and R compared to fine powder. On this basis sheet from coarse powder would be expected to be more formable than fine powder (15 μM) sheet. This potentially favorable forming characteristic may be related in part to the fine grain size of the coarse powder sheet after 1 hour at 920 F (Table 86).

MA65, MA66, and MA67 showed only pitting attack in ExCO even when exposed for twice as long as the standard test for 7XXX alloys (Table 89).

3. Conclusions.

a. P/M MA65 developed similar strength and tear properties to I/M 7075.

b. I/M 7050 alloy developed superior strength with good fracture toughness compared to the P/M alloys and I/M 7075.

c. P/M 0.090" sheet was not susceptible to exfoliation corrosion at up to 88 ksi yield strength.

d. Coarse powder gave finer grain size in sheet compared to fine powder.

SUMMARY OF CONCLUSIONS

1. Alloy MA66 (Al-8 Zn-2.5 Mg-1 Cu) in extrusions achieved the strength, ductility, fracture toughness, resistance to stress-corrosion cracking and exfoliation required for the Target B combination of properties, at 85 ksi longitudinal yield strength (LYS) (Table 90).

2. Alloy MA67 (Al-8 Zn-2.5 Mg-1 Cu-1.6 Co) in extrusions fabricated from argon preheated compacts had the strength, resistance to SCC and exfoliation, and fatigue performance required for the Target A combination of properties, at 95 ksi LYS (Table 91). This alloy did not meet the elongation (11%) and fracture toughness (K_{IC} = 26 ksi$\sqrt{in.}$) objectives for Target A.

3. Alloy MA66 in extrusions achieved the strength, ductility, fracture toughness, exfoliation resistance and fatigue performance goals of the Target A combination of properties, at 95 ksi LYS (Table 91). This alloy-temper did not meet the SCC goal for Target A.

4. Vacuum preheating and compacting substantially improved the longitudinal and transverse fracture toughness of P/M extrusions when compared to extrusions from argon or nitrogen atmosphere preheated compacts.

5. Vacuum preheated MA83 (high purity base Al-8 Zn-2.5 Mg-1 Cu) extrusions surpassed the transverse plane-strain

fracture toughness (K_{Ic}) and ductility of I/M (Ingot Metallurgy) 7050 and 7075 extrusions.

6. P/M MA67 alloy developed a superior combination of strength and SCC resistance compared to I/M 7075, 7178 and 7001 alloys in extrusions.

7. P/M MA67 alloy developed a superior combination of strength and SCC resistance compared to I/M 7050, 7049, and 7075 alloys in die forgings.

8. P/M MA67 alloy developed a superior combination of strength and SCC resistance compared to I/M 7075 alloy in hand forgings.

9. P/M MA67 alloy developed a superior combination of strength and SCC resistance compared to 7050 and 7075 alloys in plate.

10. P/M MA65, MA66, and MA67 alloys all developed superior combinations of strength and resistance to stress-corrosion cracking compared to I/M 7075 alloy in die forgings, plate, extrusions, and hand forgings.

11. P/M extrusions at up to 95 ksi LYS and P/M 0.090" sheet at up to 88 ksi LYS was resistant to exfoliation corrosion, based on ExCO accelerated total immersion test. I/M extrusions 7001, 7178, and 7075 all showed inferior combinations of strength and exfoliation resistance compared to P/M alloy extrusions.

12. P/M MA66 and MA67 extrusions sustained up to 40% higher fatigue stress than commercial 7075-T6510 without failure in notched fatigue tests ($K_t = 3$, $R = 0.0$, 10^8 cycles).

13. P/M MA65 extrusions developed smooth specimen fatigue performance superior to 7075-T6 extrusions at equal yield strength.

14. P/M MA66 and MA67 extrusions developed smooth and notched specimen fatigue performance superior to 7001-T6 and 7075-T6.

15. P/M MA65 sheet developed comparable strength and fracture toughness (tear properties) to I/M 7075-T6 sheet.

16. P/M alloy die forgings, plate and hand forgings fabricated from argon preheated compacts had inferior fracture toughness compared to I/M 7075 alloy. Vacuum preheating is expected to substantially improve fracture toughness when applied to these products.

17. Transverse fracture toughness and ductility in extrusions is strongly dependent on extrusion density, associated porosity and porosity distribution.

18. Fine powder of irregular shape (as atomized in air) provided maximum extrusion density, transverse ductility and fracture toughness in extrusions from inert gas preheated compacts.

19. Hot pressed compacts from fine powders had superior forgeability, ductility and fracture toughness in open die hand forgings compared to coarse powder compacts.

20. Among inert gas preheats, maximum transverse fracture toughness was achieved by furnace or retort preheating followed by bare compact hot pressing preceding hot working. Exposure to air in transferring compact from furnace or retort to compacting cylinder should be minimized to prevent oxidation of the compact near the compact surface.

21. Increasing amounts of hot reduction substantially improved transverse fracture toughness of hand forgings from hot pressed compacts prepared with argon preheating, by closing up residual interparticle porosity present in the hot pressed compacts.

22. Scalping of hot pressed compacts prepared with argon preheating is necessary prior to hand forging to remove the oxidized surface layer and thus minimize surface cracking during hot forging.

23. Nitrogen gas preheating gave superior degassing of green compacts compared to argon preheating and resulted in hand forgings with superior transverse fracture toughness compared to hand forgings from argon preheated compacts.

24. Preheating green compacts in nitrogen or argon prior to hot pressing improved forgeability and mechanical properties over preheating without a flowing inert gas.

REFERENCES

1. Lyle, J. P., Jr., "Development of Aluminum Base Alloys - Section I Final Report," Contract No. DA-36-034-ORD-3559 RD, September 7, 1966.

2. Haarr, A. P., "Development of Aluminum Base Alloys - Section II Final Report," Contract No. DA-36-034-ORD-3559 RD, December 20, 1965.

3. Haarr, A. P., "Development of Aluminum Base Alloys - Section III Final Report," Contract No. DA-36-034-ORD-3559 RD, May 31, 1966.

4. Cebulak, W. S., and Truax, D. J., "Program to Develop High-Strength Aluminum Powder Metallurgy Products - Phase I - Process Optimization - Final Report," Contract No. DAAA25-70-C0358, March 12, 1971, AD882-137L.

5. Cebulak, W. S., and Truax, D. J., "Program to Develop High-Strength Aluminum Powder Metallurgy Products - Phase II - P/M Alloy Optimization - Final Report," Contract No. DAAA25-70-C0358, June 1, 1971, AD884-642L.

6. Lyle, J. P., Jr., and Cebulak, W. S., "Properties of High-Strength Aluminum P/M Products," presented at The Third Air Force Metal Working Conference, Western Metal and Tool Exposition, March 13-16, 1972, Los Angeles, California.

7. Kaufman, J. G., and Hunsicker, H. Y., "Fracture Toughness Testing at Alcoa Research Laboratories," Symposium on Fracture Toughness Testing and Its Applications, 1965, ASTM Special Technical Publication No. 381.

8. Sprowls, D. O., Walsh, J. D., Shumaker, M. B., "Simplified Exfoliation Testing of Aluminum Alloys," presented at Symposium on Localized Corrosion, ASTM Annual Meeting, Atlantic City, June 1971.

9. Kaufman, J. G., Schilling, P. E., Nordmark, G. E., Lifka, B. W., and Coursen, J. W., "Fracture Toughness, Fatigue and Corrosion Characteristics of X7080-T7E41 and 7178-T651 Plate and 7075-T6510, 7075-T73510, X7080-T7E42 and 7178-T6510 Extruded Shapes," AFML-TR-69-255, Contract No. F33615-67-C-1521, November 1969.

10. Kahlow, Kurt J., and Avitzur, Betzalel, "Void Behavior as Influenced by Pressure and Plastic Deformation," Lehigh University, October 1971.

REFERENCES (CONTINUED)

11. Staley, J. T., "Exploratory Development of High-Strength Stress-Corrosion Resistant Aluminum Alloys Usable in Thick Section Applications," Air Force Contract No. F33615-69-C-1644, Phase II, to be reported in Final Report.

12. Kunkle, D. A., and Willey, L. A., "Densities of Wrought Aluminum Alloys," Journal of Materials, Vol 1, No. 1, March 1966, p 226.

13. Hunsicker, H. Y., "The Metallurgy of Heat Treatment," Aluminum, Vol. 1, American Society for Metals, Metals Park, Ohio, 1967, p 139.

14. Summerson, T. J., and Luhan, J. V., "Development of 7049-T73 High-Strength, Stress-Corrosion Resistant Aluminum Alloy Forgings," presented at 1970 WESTEC, Los Angeles, March 11, 1970.

15. Staley, J. T., and Hunsicker, H. Y., "New Aluminum Alloy X7050," presented at ASM Metals Congress, Detroit, Michigan, October 18-20, 1971.

16. Staley, J. T., "Investigation to Develop a High-Strength Stress-Corrosion Resistant Naval Aircraft Aluminum Alloy - Final Report," Naval Air Systems Command Contract No. N00019-69-C-0292, November 20, 1970.

17. Nelson, P. G., and Winlock, J., "A Method of Determining the Percentage Elongation at Maximum Load in the Tension Test," ASTM Bulletin, January 1949, p 53.

18. Rogers, R. W., Jr., and Anderson, W. A., "Effect of Plastic Anisotropy on Drawing Characteristics of Aluminum Alloy Sheet," Metal Forming: Interrelation Between Theory and Practice, Plenum Publishing Corporation, New York, 1971, p 185.

19. Kaufman, J. G., and Holt, Marshall, "Fracture Characteristics of Aluminum Alloys," Alcoa Research Laboratories Technical Papter No. 18, Aluminum Company of America, Pittsburgh, Pennsylvania, 1965.

20. Private communication with J. T. Staley, June 19, 1972.

21. Aluminum Standards and Data, The Aluminum Association, New York, New York, December 1969.

Table 1

TARGET A

Property	Target	Measured Properties 9.0 Zn-2.5 Mg-1.0 Cu
Y.S. (ksi)	95	94.8
K_{Ic} ksi$\sqrt{\text{in.}}$	26	19[2]
SCC (ksi)	25	<25
Fatigue[1] (ksi)	22	30
Exfoliation	Resistant	Immune
Elongation (%)	11	8

Notes: 1. Endurance limit for smooth specimen, rotating beam.
2. Estimated from NTS/YS.

WSC:km
8-3-72

Table 2

TARGET B

Property	Target	Measured Properties 6.5 Zn-2.3 Mg-1.5 Cu
Y.S. (ksi)	85	84.5
K_{Ic} (ksi$\sqrt{\text{in.}}$)	26	28[4]
SCC (ksi)	25	40
Fatigue[1] (ksi)		
Smooth rotating beam	22	30
Smooth axial stress[2]	34	--
Notched axial stress[3]	14	--
Exfoliation	Immune	Immune
Elongation (%)	11	13.5

Notes: 1. Endurance limit.
2. Stress ratio (R) = 0.0.
3. R = 0.0, K_t = 3.
4. Estimated from NTS/YS.

WSC:km
8-3-72

Table 3

TARGET C

Property	Target	Measured Properties 5.5 Zn-2.0 Mg-2.0 Cu
Y.S. (ksi)	75	75.2
K_{Ic} (ksi√in.)	45	33[2]
SCC (ksi)	42	40
Fatigue[1] (ksi)	22	25
Exfoliation	Immune	Immune
Elongation (%)	11	15

Notes: 1. Endurance limit for smooth specimen, rotating beam test.
2. Estimated from NTS/YS.

WSC:km
8-3-72

Table 4

STRENGTH AND STRESS CORROSION PERFORMANCE -
TARGET A VS Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co
2" DIAMETER EXTRUSIONS

	Longitudinal	Transverse	
	Y.S.	Y.S.	SCC (sustained stress)
Target A	95 ksi	--	25 ksi
Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co	95	81 ksi	5/5 Pass at 25 ksi[1]

Note: 1. S/N = Specimens Surviving/Specimens Tested for 910 days in New Kensington Atmosphere. 3/5 Pass 910 days with 40 ksi applied stress.

WSC:dk
8-16-72

Table 5

COMPOSITION OF ALLOYS FOR SCALED UP PRODUCT EVALUATION

Sample No.	Alloy	Powder Size[10] µM	Pot No.	Weight %[7] Si	Fe	Cu	Mg	Zn	Be	Co	Ni	Ti	Cr
404877[1]	MA65	15.6	1537-8	.06	.05	1.53	2.26	6.46	.002	.00	.00	.00	.00
404878[2]	MA65	23.9	1540	.06	.05	1.57	2.34	6.43	.002	.00	.00	.00	.00
404879[2]	MA65	48.5	1539	.06	.04	1.55	2.36	6.42	.002	.00	.00	.00	.00
404880[3,6]	MA66	16.5	1541	.05	.04	1.09	2.56	7.92	.003	.00	.00	.00	.00
404881[4]	MA66	21.8	1543	.05	.04	1.08	2.54	8.37	.003	.00	.00	.00	.00
404882[4]	MA66	49.3	1542	.05	.04	1.06	2.56	8.34	.003	.00	.00	.00	.00
405481[9]	MA83	13.6	1566	.01	.01	1.03	2.52	8.19	.002	.00	.00	.00	.00
404883[5]	MA67	14.7	1544	.05	.06	1.03	2.64	8.28	.002	1.52	.02	.00	.00
404884[5]	MA67	22.7	1546	.05	.06	1.02	2.49	7.82	.003	1.61	.02	.00	.00
404885[5]	MA67	51.2	1545	.05	.06	1.02	2.51	7.86	.003	1.64	.02	.00	.00
405241-1[8]	7001	Ingot		.07	.16	1.93	2.77	7.16	.002		.00	.01	.20
405295-4[9]	7075	Ingot		.10	.18	1.66	2.40	5.75	.002		.00	.03	.20
405297-4[9]	7178	Ingot		.12	.20	1.86	2.45	6.56	.002		.00	.03	.19

Notes:
1. Analytical Chemistry J. O. 71-041904.
2. Analytical Chemistry J. O. 71-042004.
3. Analytical Chemistry J. O. 71-041312.
4. Analytical Chemistry J. O. 71-042607.
5. Analytical Chemistry J. O. 71-042901.
6. Analytical Chemistry J. O. 71-062503.
7. Cr = Mn = Ti = 0.00%, except as noted.
8. Analytical Chemistry J. O. 71-100503, Mn=0.02.
9. Analytical Chemistry J. O. 71-081608, Mn=0.04.
10. Average Particle Diameter from Fisher Sub-Sieve Sizer.

Table 6

FABRICATION OF HOT PRESSED 170-LB COMPACTS

1.	Melt and Alloy	- See Table 5 for Compositions.
2.	Atomize	- See Table 8 for Powder Sizes, Screen Analyses.
3.	Scalp Powders	- See Table 8 for Scalping Screens.
4.	Cold Compact Powders	- Isostatically cold pressed at 30 ksi to yield green compact 8" diameter x 42 " long. Compacts 76-80% of theoretical density. See Table 9 for observed compact densities.
5.	Preheat Compacts	- Heat in flowing argon in a controlled atmosphere furnace.
6.	Hot Press	- Immediately after preheat, hot press at 90 ksi in a Tapered Cylinder (see Figure 2) to yield a 8.4 to 9.2" diameter x 28" long compact.

Table 7

FABRICATING CONDITIONS FOR EXTRUSION BILLETS

Sample No.	Powder Size[1] uM	Approx. Cold Compact Density %[2]	Preheat Conditions: Method[3]	Preheat Conditions: Time hrs	Preheat Conditions: Temp °F	Preheat Conditions: Gas	Preheat Conditions: Flow CFH/lb	Hot Compact Pressure ksi	Scalped Billet[4]: Dia. in.	Scalped Billet[4]: Length[5] in.
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu										
404877-E1	15.6	78	Furnace	2.3	1000	Argon	0.29	90	7.2	25
404879-E2	48.5	80	Furnace	1.0	1000	Argon	0.29	90	7.2	25
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu										
404880-E3	16.5	78	Furnace	1.2	1000	Argon	0.29	90	7.2	25
MA83 Alloy: High Purity Al-8.0 Zn-2.5 Mg-1.0 Cu										
405481-E7	13.6	77	Furnace	2.0	1000	Argon	0.29	90	7.2	25
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co										
404883-X4	14.7	76	Furnace	1.9	1000	Argon	0.29	90	7.2	25
404883-E5	14.7	76	Furnace	1.6	1000	Argon	0.29	90	7.2	25
404885-E6	51.2	77	Furnace	1.0	1000	Argon	0.29	90	7.2	25

Notes:
1. APD from Fisher Sub-Sieve Sizer.
2. Percent of Theoretical Density - from Table 9.
3. Preheated in a muffle atmosphere furnace immediately before hot pressing.
4. Hot pressed compact: 8.3" to 9.2" diameter (tapered) x 28" long.
5. Equal amounts scalped from each end of hot pressed billet.

WSC:km
8-8-72

Table 8

POWDER SCREEN ANALYSIS OF ALLOYS
FOR SCALED UP PRODUCT EVALUATION

Sample No.	Alloy	Pot No.	Date Atomized	APD[3] uM	U.S. Standard Screen Analysis (Wt. %)[1] -30+50	-50+100	-100+200	-200+325	-325	Scalping Screen (Tyler) Mesh
404877	MA65	1537-8	4-14,16-71	15.6	0.0	0.0	4.6	11.8	83.6	100
404878	MA65	1540	4-19-71	23.9	2.9	14.8	20.6	16.3	45.4	48
404879	MA65	1539	4-19-71	48.5	15.4	35.9	28.1	11.7	8.9	24
404880	MA66	1541	4-21-71	16.5	0.0	0.0	5.6	13.0	81.4	100
404881	MA66	1543	4-23-71	21.8	2.8	16.0	22.0	16.2	43.0	48
404882	MA66	1542	4-23-71	49.3	13.0	34.6	29.3	13.2	9.9	24
405481	MA83	1566	8-13-71	13.6	0.0	0.0	1.2	7.3	91.5	100
404883	MA67	1544	4-26-71	14.7	0.0	0.0	3.2	9.5	87.4	100
404884	MA67	1546	4-28-71	22.7	2.0	14.6	21.7	16.3	45.4	48
404885	MA67	1545	4-28-71	51.2[2]	12.9	35.3	29.6	12.9	9.1	24

Notes:
1. Screen Analysis made after scalping.
2. 50μM maximum scale reading. APD estimated.
3. Average Particle Diameter from Fisher Sub-Sieve Sizer.

WSC:km
8-3-72

Table 9

EFFECT OF ALLOY AND POWDER
SIZE ON COMPACT GREEN DENSITY

Alloy	Theoretical Density[4] lbs/in.^{3}	Compact Green Density[1] Powder Size[2] 15	23	50	Powder Natural Age Time[3] Days
MA65: 6.5 Zn-2.3 Mg-1.5 Cu	0.1019	78	80	80	21-26
MA66: 8.0 Zn-2.5 Mg-1.0 Cu	0.1025	78	77	76	20-21
MA67: 8.0 Zn-2.5 Mg-1 Cu-1.6 Co	0.1031	76	76	77	15-16

Notes:
1. Percent of theoretical density. All compacts cold pressed at 30 ksi in a wet bag isostatic cylinder to approximately 8" dia. x 42" long.
2. Average Particle Diameter (μM) from Fisher Sub-Sieve Sizer.
3. Time between atomizing and cold compacting.
4. Calculated from Ref. 12.

WSC:km
8-3-72

Table 10

EXTRUSIONS CONDITIONS FOR
1/2" x 6-3/8" AND OCTAGONAL BAR EXTRUSIONS

			1/2" x 6-3/8" Extrusion[1]			Octagonal Extrusion[1]		
S. No.	Alloy	Powder Size[2] uM	Piece No.	Extrusion Breakout Pressure ksi	Extrusion No.	Piece No.	Extrusion Breakout Pressure ksi	Extrusion No.
404877	MA65	15.6	E1R	86.9	6163	E1BD	78.8	6169
404879	MA65	48.5	E2R	85.6	6164	E2BD	81.5	6170
404880	MA66	16.5	E3R	84.2	6165	E3BD	77.4	6171
405481	MA83	13.6	E7R	79.9	6628	E7BD	68.6	6629
404883	MA67	14.7	X4R	86.9	6166	X4BD	82.8	6172
404883	MA67	14.7	E5R	88.3	6167	E5BD	86.9	6173
404885	MA67	51.2	E6R	86.9	6168	E6BD	84.2	6174
405241	7001[3]	--	-1	89.6	6160	-2	([4])	6157
405295	7075[3]	--	-4	89.6	6161	-5	92.4	6159
405297	7878[3]	--	-4	89.6	6162	-3	99.6	6158

Notes:
1. Billets 7-1/2"diameter x 12-1/2" lg. reheated to 700 F and extruded to indicated section from a 7-1/2" dia. extrusion cylinder at less than 3 feet/minute extrusion speed. 1/2" x 6-3/8" has extrusion ratio = 13.9. Octagonal extrusion ratio = 17.1.
2. Average Particle Diameter from Fisher Sub-Sieve Sizer.
3. Extrusions fabricated from D.C. ingot (9" diameter for 7001 and 7178, 11" diameter for 7075), scalped to 7-1/2" diameter.
4. Not measured.

WSC:km
8-3-72

Table 11

EFFECT OF SECOND-STEP AGING TIME ON
LONGITUDINAL PROPERTIES OF OCTAGONAL EXTRUSIONS

Sample No.	Powder Size[1] μM	Second-Step Age[2] @ 325 F	Longitudinal Properties T.S. ksi	Y.S. ksi	% El. in 4D	RA %	E.C. % IACS
MA65 Alloy: 6.5 Zn-2.3 Mg-1.5 Cu							
404877-E1S1	15.6	None	99.2	86.1	8.0		34.7
404877-E1S2	15.6	2 hrs.	90.3	83.9	10.0		38.8
404877-E1S3	15.6	13 hrs.	85.0	79.2	14.0		42.4
404877-E1S6	15.6	16 hrs.	78.2	71.4	12.8	32	
404877-E1S4	15.6	20 hrs.	75.2	67.5	13.0	34	
404879-E2S4	48.5	None	88.9	83.2	14.0	27	32.2
404879-E2S5	48.5	2 hrs.	89.0	86.0	13.0	33	34.5
404879-E2S3	48.5	13 hrs.	84.2	78.6	16.0		38.5
404879-E2S6	48.5	16 hrs.	84.2	79.9	14.5	40	
404879-E2S7	48.5	20 hrs.	79.2	73.2	15.5	46	
MA66 Alloy: 8.0 Zn-2.5 Mg-1.0 Cu							
404880-E3S1	16.5	None	100.8	95.1	12.0		34.0
404880-E3S2	16.5	6 hrs.	88.9	84.9	16.0		41.1
404880-E3S3	16.5	16 hrs.	81.4	76.3	16.0		43.9
MA67 Alloy: 8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co							
404883-X4S1	14.7	None	104.2	98.9	12.0		32.3
404883-X4S2	14.7	6 hrs.	90.2	86.0	13.0		38.7
404883-X4S3	14.7	16 hrs.	83.9	77.6	14.0		41.0
404883-E5S1	14.7	None	103.4	97.4	10.0		[illegible]
404883-E5S2	14.7	6 hrs.	89.7	84.4	11.0		[illegible]
404883-E5S3	14.7	16 hrs.	83.4	76.4	14.0		40.9
404885-E6S1	51.2	None	108.5	103.4	12.0		30.3
404885-E6S2	51.2	6 hrs.	97.2	91.2	10.0		34.8
404885-E6S3	51.2	16 hrs.	88.6	83.2	12.0		37.6

Notes: 1. Average Particle Diameter from Fisher Sub Sieve Sizer.
2. Solution heat treated 2 hours @ 920 F, cold water quenched, aged 4-7 days @ room temperature + 24 hours @ 250 F + second-step aging as shown.

WSC/lmk
8/11/72

Table 12

TENSILE PROPERTIES OF P/M AND I/M OCTAGONAL EXTRUDED BAR (EXTRUSION RATIO = 17.1:1)

Sample No.	Powder Size[1] µM	Preheat Atmos-phere[2]	Second-Step Age[3] hrs. @ 325 F	Electrical Conduc-tivity % IACS	Longitudinal Properties T.S. ksi	Longitudinal Y.S. ksi	Longitudinal % El. in 4D	Longitudinal R of A	Longitudinal NTS ksi	Longitudinal NTS/YS	Transverse Properties T.S. ksi	Transverse Y.S. ksi	Transverse % El. in 4D	Transverse R of A	Transverse NTS ksi	Transverse NTS/YS
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu																
404877E1B	15.6	Argon	0[4]	38.1	94.5	86.7	8.8	10	109.8	1.27	83.6	72.4	8.6	8	54.2	0.75
404877E1C	15.6	Argon	14	43.2	82.3	76.6	11.0	18	96.6	1.26	75.8	68.2	8.6	16	57.0	0.84
404879E2B	48.5	Argon	None	32.3	89.4	84.0	14.0	21	114.5	1.36	84.2	73.1	7.0	5	53.1	0.73
404879E2C	48.5	Argon	19	39.7	81.0	75.8	15.0	40	106.9	1.41	76.4	70.0	5.4	6	56.6	0.81
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu																
404880E3B	16.5	Argon	0[4]	33.6	98.3	94.3	8.0	9	117.4	1.25	86.1	78.7	9.4	7	52.2	0.66
404880E3C	16.5	Argon	6	40.7	87.2	84.2	11.2	26	107.7	1.28	80.1	74.2	9.4	22	49.3	0.66
404882C	49.3	Nitrogen[7]	6	31.0	92.4	90.2	11.7	27	93.2	1.03	83.1	80.8	1.6	3	34.6	0.43
MA83 Alloy: High Purity Al-8.0 Zn-2.5 Mg-1.0 Cu (0.02 max. ea. Fe, Si)																
405081E7C	13.6	Argon	None	33.4	97.3	92.6	8.0	--	117.5	1.27	86.0	76.8	11.7	19	59.8	0.78
MA67 Alloy: Al-3.0 Zn-2.5 Mg-1.0 Cu																
404883X4C	14.7	Argon	None	31.6	104.8	98.5	7.5	--	76.1	0.77	90.8	82.4	3.5	3	40.0	0.49
404883E5C	14.7	Argon	None	31.6	102.6	97.8	9.0	--	78.4	0.80	91.8	82.6	4.3	2	38.0	0.46
404883E5B	14.7	Argon	0.5	33.5	99.6	95.9	7.8	11	88.2	0.92	89.8	82.8	7.4	14	43.7	0.53
404883X4B	14.7	Argon	1	34.0	98.4	94.9	7.3	16	85.0	0.90	89.1	83.4	3.9	5	46.0	0.55
404885E6C	51.2	Argon	None	30.1	107.2	103.9	8.5	--	85.8	0.83	87.7	82.2	3.1	1	35.5	0.43
404885E6B	51.2	Argon	3	33.5	99.8	97.4	7.8	14	83.8	0.86	88.6	84.3	2.3	2	34.3	0.41
7001 Alloy: Al-7.2 Zn-2.8 Mg-1.9 Cu-0.2 Cr																
4052412C	I/M[5]	---	None	30.5	103.8	98.8	7.0		3.2	1.15	87.8	79.3	4.7	7	53.3	0.67
7178 Alloy: Al-6.6 Zn-2.4 Mg-1.9 Cu-0.2 Cr																
4052973C	I/M[5]	---	None	31.7	97.8	91.2	9.2	12	114.8	1.26	83.6	73.9	6.2	7	65.0	0.88
4052973A	I/M[5]	---	9.5	37.4	85.9	79.9	10.2	24	102.4	1.28	76.8	70.5	7.0	10	63.2	0.90
7075 Alloy: Al-5.8 Zn-2.4 Mg-1.7 Cu-0.2 Cr																
405295 5C	I/M[6]	---	None	30.7	98.6	86.9	10.5	13	114.0	1.31	80.4	71.8	8.0	8	75.5	1.05
405295 5AB	I/M[6]	---	24	40.0	80.2	73.4	12.5	34	99.2	1.35	72.4	63.9	8.0	13	73.6	1.15

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Isostatically pressed 170 lb. green compact preheated to 1000 F in flowing argon, hot pressed at 90 ksi, scalped, reheated and extruded, except as noted.
3. Solution heat treated 2 hours @ 920 F (P/M) or 4 hours @ 870 F (I/M), cold water quenched (no stress relief), naturally aged 4-7 days + 24 hours @ 250 F.
4. Heated up to 325 F, no hold @ 325 F.
5. I/M = Ingot Metallurgy. From 9" diameter D.C. ingot (production plant cast).
6. I/M = Ingot Metallurgy. From 11" diameter D.C. ingot (production plant cast).
7. 15 lb. compact preheated in a retort with flowing N_2, hot pressed at 90 ksi, extruded with 12.4 extrusion ratio. SHT 2 hrs. @ 920 F, CWQ, aged 24 hours @ 250 F + 6 hours @ 325 F (from Table 43).

WSC/lmk

Table 13

MECHANICAL PROPERTIES OF P/M AND I/M 1/2"x6-3/8" EXTRUDED BAR (EXTRUSION RATIO = 13.9:1)

					Longitudinal Properties							Long-Transverse Properties						
Sample No.	Powder Size[1] µM	Preheat Atmosphere[2]	Second-Step Age[3] hrs @ 325 F	E.C. % IACS	T.S. ksi	Y.S. ksi	El. % in 4D	RA %	Tear Str. ksi	Tr.S./Y.S.[5]	UPE[10]	T.S. ksi	Y.S. ksi	El. % in 4D	RA %	Tear Str. ksi	Tr.S./Y.S.	UPE[10]
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu																		
404877E1A	15.6	Argon	None	35.3	89.9	81.2	12.5	12	63.7	0.78	275[4]	86.6	76.2	14.0	22	51.2	0.67	95
404877E1C	15.6	Argon	6	44.6	77.2	67.2	12.0	18	81.0	1.21	307[4]	74.4	64.8	13.0	--	55.8	0.86	160
404879E2B	48.5	Argon	None	35.0	88.8	83.3	14.0	24	82.2	0.99	400	82.0	75.1	15.0	28	69.5	0.93	185
404879E2C	48.5	Argon	16	41.0	79.1	73.3	16.0	42	83.8	1.14	495	78.0	71.1	13.5	34	60.0	0.84	140
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu																		
404880E3B	16.5	Argon	None	35.1	93.9	87.6	11.5	17	74.9	0.86	N.D.[6]	92.0	84.4	13.5	20	61.1	0.72	~0
404880E3A	16.5	Argon	3	39.7	87.0	81.2	12.0	24	84.6	1.04	N.D.[6]	83.6	77.2	13.0	26	59.9	0.78	~0
MA83 Alloy: High Purity Al-8.0 Zn-2.5 Mg-1.0 Cu (0.02% Max. ea. Fe, Si)																		
405481E7B	13.6	Argon	None	35.4	93.0	86.9	12.0	14	75.0	0.86	N.D.[6]	90.3	82.8	14.0	25	63.6	0.77	250
405481E7A	13.6	Argon	3	41.1	85.1	79.1	13.0	26	97.5	1.23	N.D.[6]	83.0	77.2	14.0	35	58.7	0.76	150
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co																		
404883X4B	14.7	Argon	None	33.7	100.8	96.2	8.5	15	56.1	0.58	125	98.4	90.1	10.0	19	55.5	0.62	~0
404883E5B	14.7	Argon	None	33.0	100.0	94.3	9.0	8	58.0	0.62	202[4]	96.4	88.4	9.0	--	48.0	0.54	~0
404883X4A	14.7	Argon	4	32.3	88.2	79.6	10.5	21	83.2	1.05	N.D.[6]	85.4	77.0	11.0	28	58.3	0.76	~0
404883E5A	14.7	Argon	5	39.0	86.0	77.7	10.5	28	75.6	0.97	N.D.[6]	84.5	76.4	12.0	27	50.7	0.66	85
404885E6B	51.2	Argon	None	31.2	101.2	97.0	8.5	8	56.4	0.58	125	98.4	89.1	10.0	18	53.7	0.60	~0
404885E6A	51.2	Argon	7	37.5	87.4	78.8	12.0	26	64.4	0.82	160	86.8	77.4	11.0	21	54.0	0.70	~0
7001 Alloy: Al-7.2 Zn-2.8 Mg-1.9 Cu-0.2 Cr																		
405241-1B	I/M[7]	--	None	31.6	100.0	92.8	9.0	10	62.6	0.67	150	95.4	86.4	12.0	14	59.5	0.69	~0
7178 Alloy: Al-6.6 Zn-2.4 Mg-1.9 Cu-0.2 Cr																		
405297-4C	I/M[7]	--	None	31.3	91.2	83.6	11.0	12	66.8	0.80	190[4]	87.4	78.4	12.0	16	54.9	0.70	100
405297-4B	I/M[7]	--	10	38.0	82.2	72.8	11.0	19	75.6	1.04	270[4]	80.0	70.7	11.5	21	64.2	0.91	145
7075 Alloy: Al-5.8 Zn-2.4 Mg-1.7 Cu-0.2 Cr																		
405295-4C	I/M[8]	--	None	32.3	88.4	80.2	11.0	15	83.5	1.04	345	83.0	74.2	13.0	25	79.8	1.08	245
405295-4B	I/M[8]	--	24	40.3	77.6	67.3	12.5	25	82.0	1.22	386[4]	75.7	65.2	13.0	28	78.4	1.20	205

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Isostatically pressed green compacts preheated to 1000 F in flowing argon, hot pressed at 90 ksi, scalped, reheated and extruded.
3. Extrusions solution heat treated 2 hours @ 920 F (P/M) or 4 hours @ 870 F (I/M), cold water quenched, stretched 2%, aged 4 days at room temperature + 24 hours @ 250 F + further aging @ 325 F as shown.
4. Diagonal fracture (result from one test).
5. Tear Strength/Tensile Yield Strength.
6. N.D. = Not determined because of non-standard fracture.
7. I/M = Ingot Metallurgy. From 9" dia. D.C. ingot (production plant cast).
8. I/M = Ingot Metallurgy. From 11" dia. D.C. Ingot (production plant cast).
9. % Stretch.
10. Unit Propagation Energy - in.-lbs/in.^{2}.

Table 14

STRESS-CORROSION PERFORMANCE OF OCTAGONAL EXTRUSIONS IN 3.5% NaCl
ALTERNATE IMMERSION TEST - FEDERAL TEST METHOD 823

Specimen No.	Powder Size[1] μM	Second-Step Age[2] @ 325 F	LYS ksi	TYS ksi	Days to Fracture at Indicated[3] Stress Level in A.I. Test: 25 ksi	30 ksi	35 ksi	40 ksi	45 ksi
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu									
404877-E1B	15.6	None	86.7	72.4	6,24,25	5,5,12	7,7,7	4,4,5	5,5,7
404877-E1C	15.6	14 hrs.	76.6	68.2	P,P,P	P,P,P	P,P,P	68,68,72	56,66,73
404879-E2B	48.5	None	83.9	73.1	6,16,18	6,16,34	6,6,6	4,4,6	4,4,5
404879-E2C	48.5	19 hrs.	75.8	70.0	68,73,83	36,53,74	16,18,33	6,24,29	12,12,16
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu									
404880-E3B	16.5	None	94.3	78.7	24,26,34	19,24,24	19,19,20	8,10,16	7,8,8
404880-E3C	16.5	6 hrs.	84.2	74.2	P,P,P	61,75,P	45,52	33,43,45	20,24,27
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co									
404883-X4B	14.7	1 hr.	94.9	83.4	P,P,P	8,19,84	18,18,29	11,12,19	3,6,11
404883-E5B	14.7	.5 hr.	95.9	82.8	P,P,P	43,P,P	19,34,36	9,10,11	2,2,18
404885-E6B	51.2	3 hrs.	97.4	84.3	71,73,83	19,29,29	6,7,11	5,7,10	4,6,6
7075 Alloy: Al-5.8 Zn-2.4 Mg-1.7 Cu-0.2 Cr									
405295-5C	I/M	None	86.9	71.8	43,57,60	4,6,29	3,3,6	3,3,4	2,3,3
405295-5B	I/M	24 hrs.	73.4	63.9	P,P,P	P,P,P	P,P,P	75,76,78	61,73,82
7178 Alloy: Al-6.6 Zn-2.4 Mg-1.9 Cu-0.2 Cr									
405297-3C	I/M	None	91.2	73.9	36,36,48	24,28,39	11,22,27	17,17,22	4,4,18
405297-3B	I/M	9.5 hrs.	79.9	70.5	P,P,P	P,P,P	84,84,P	72,75,P	53,63,75
7001 Alloy: Al-7.2 Zn-2.8 Mg-1.9 Cu-0.2 Cr									
405241-2C	I/M	None	98.8	79.3	39,39,63	29,33,42	11,22,24	3,3,11	2,3,4

Notes:
1. Average Particle Diameter.
2. First-step aged 24 hrs. @ 250 F.
3. P = pass - did not fail in 84 day exposure in A.I.

WSC/lmk
8/11/72

Table 15

NOTCHED SPECIMEN (K_t=3) AXIAL STRESS FATIGUE PERFORMANCE OF OCTAGONAL EXTRUSIONS (STRESS RATIO = 0.0)

Alloy	Specimen No.	Powder Size[2] µM	LYS ksi	Kilocycles to Failure at Maximum Stress Indicated[1] 15 ksi	17 ksi	17.5 ksi	18.5 ksi	20 ksi	21 ksi	22.5 ksi	25 ksi	30 ksi
MA65	404877-E1A	15.6	86.7	111,285+		47,880+	26,492	387				
MA65	404879-E2A	48.5	84.0	62,350+								19
7075	405295-5D	Ingot	86.9	31,237+	73,826+		9,327	67				14
MA66	404880-E3C	16.5	84.2				8,772+[3]					
MA66	404880-E3A	16.5	94.3	86,484+				101,523+	103,304+	735		16
MA83	405381-E7B	13.6	92.6	102,356+	68,976+			737				18
MA67	404883-X4A	14.7	94.9	77,031+						14,911	2,015	
MA67	404883-E5A	14.7	95.9	103,260+				50,708+				45
7001	405241-2A	Ingot	98.8	106,195+				16,041				12

Notes:
1. Samples with "+" did not fail.
2. Average Particle Diameter from Fisher Sub-Sieve Sizer.
3. In test.

WSC/dld
10/3/72

Table 16

SMOOTH SPECIMEN AXIAL STRESS FATIGUE PERFORMANCE OF OCTAGONAL EXTRUSIONS (STRESS RATIO = 0.0)

Alloy	Specimen No.	Powder Size[3] μM	LYS ksi	Kilocycles to Failure at Maximum Stress Indicated[2] 30 ksi	32 ksi	34 ksi	37 ksi	41 ksi	45 ksi	50 ksi	60 ksi	70 ksi
MA65	404877E1A	15.6	86.7									
MA65	404879E2A	48.5	84.0	419		125,217+	10,933[1]	7,518 47	24,250[1]	374	47	27
7075	405295-5D	Ingot	86.9	44,196+	31,101	7269		737		111	56	
MA66	404880E3A	16.5	94.3				27,300[1] 10,788[1]	6,451 23,602[1]	848[1]	1,240[1]	10,442[1]	72
MA83	405481-E7B	1[illegible]	92.6				42,293	13,385[1] 14,700	4,796[1] 2,890[1]	210	149	
MA67	404883X4A	14.7	94.9					612	1,199[1]			
MA67	404883-E5A	14.7	95.9					643 53,600[1]	1,699 8,288[1]	74	1,956	40
MA67	404885-E6A	51.2	97.4	444				107				
7001	405241-2A	Ingot	98.8			37,988[1]	11,517 9,296[1]	10,735		60	35	22

Notes:
1. Grip failure.
2. Samples with "+" did not fail.
3. Average Particle Diameter.

Table 17

EXFOLIATION CORROSION PERFORMANCE OF 1/2" X 6-3/8" EXTRUDED BAR IN ExCO TEST FOR 48 HOURS TOTAL IMMERSION[4]

Specimen No.	Powder Size[1] µM	Second-Step Age[2] @ 325 F	Strength LYS ksi	Strength TYS ksi	Exfoliation[3,5] T/2 (E1)	Exfoliation[3,5] T/10 (E2)
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu						
404877-E1A	15.6	None	81.2	76.2	P	P
404877-E1C	15.6	16 hrs.	67.2	64.8	P	P
404879-E2B	48.5	None	83.3	75.1	P	P
404879-E2C	48.5	16 hrs.	73.3	71.1	P	P
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu						
404880-E3B	16.5	None	87.6	84.4	P	P
404880-E3A	16.5	3 hrs.	81.2	77.2	P	P
MA83 Alloy: High Purity Al-8.0 Zn-2.5 Mg-1.0 Cu						
405481-E7B	13.6	None	86.9	82.8	P	P
405481-E7A	13.6	3 hrs.	79.1	77.2	P	P
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co						
404883-X4B	14.7	None	96.2	90.1	P	P
404883-E5B	14.7	None	94.3	88.4	P	P
404883-X4A	14.7	4 hrs.	79.6	77.0	P	P
404883-E5A	14.7	5 hrs.	77.7	76.4	P	P
404885-E6B	51.2	None	97.0	89.1	P	P
404885-E6A	51.2	7 hrs.	78.8	77.4	P	P
7075						
405295-4C	Ingot	None	80.2	74.2	PB	E(A)
405295-4B	Ingot	24 hrs.	67.3	65.2	P	P
7178						
405297-4C	Ingot	None	83.6	78.4	(E(A)	E(A)
405297-4B	Ingot	10 hrs.	72.8	70.7	P	P
7001						
405241-1B	Ingot	None	92.8	86.4	E(C)	E(C)

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. First-step aged 24 hours @ 250 F.
3. Exfoliation Visual Ratings:
   - N - no appreciable attack.
   - P, PB - pitting or pit blistering.
   - E - exfoliation, A, B, C, D in order of increasing severity.
4. ExCo Test - 48 hours total immersion in 25°C solution:
   - 4 M NaCl
   - 0.5 M Potassium Nitrate
   - 0.1 M Nitric Acid
   - pH = 0.4
5. T/2 = mid-thickness plane of extrusion.
   T/10 = plane 10% of thickness below extrusion surface.

Table 18

GENERAL FABRICATING PROCEDURE FOR P/M EXTRUSIONS

Process Step		Comments
Melt and Alloy		
Atomize Molten Alloy	-	Generally atomized with air.
Scalp Powder	-	Screened to remove oversize.
Cold Compact	-	Powders cold pressed by a wet bag isostatic method with 30 to 60 ksi applied compacting pressure.
Reheat/hot press	-	All green compacts heated to 1000 F and held @ 1000 F. Immediately following preheat, compacts were hot pressed and/or hot worked.
Hot Work	-	Compacts extruded from 6-3/8" or 7-1/2" diameter cylinders.

WSC/lmk
8/16/72

Table 19

COMPOSITION OF ALLOYS FOR EFFECT OF INCREASING HOT REDUCTION ON FRACTURE TOUGHNESS

Sample No.	Pot No.	Powder Size[2] µM	Atomizing Gas	Composition[1] - Weight % Si	Fe	Cu	Mg	Zn	Zr	Co	Ni	Be	O_2[3]
405071	1549	15.6	Air	.005	.005	1.52	2.21	6.49	.00	.00	.00	.002	.355
405075	1549	45.0	Air	.00	.00	1.52	2.25	6.49	.00	.00	.00	.002	.096
404661	1527	16.0	Air	.00	.00	2.25	2.09	5.82	.11	.00	.00	.001	
404662	1527	46.0	Air	.00	.00	2.25	2.07	5.94	.11	.00	.00	.001	
404663	1526	15.3	Air	.00	.00	1.00	2.54	9.24	.00	.00	.00	.002	
404664	1526	46.0	Air	.00	.00	1.01	2.46	9.20	.00	.00	.00	.001	

Notes:
1. Mn = Cr = Ti = 0.00
2. Average Particle Diameter from Fisher Sub-Sieve Sizer.
3. Fast neutron activation analysis on powder.
4. Off Scale - Estimated.

WSC/lmk
8/3/72

Table 20

POWDER SIZE AND SCREEN ANALYSES OF ALLOY POWDERS FOR EFFECT OF INCREASED HOT REDUCTION ON FRACTURE TOUGHNESS

Sample No.	Pot No.	Date Atomized	Atomizing Gas	Powder Size[1] μM	Screen Analysis[2] - Weight % -30+50	-50+100	-100+200	-200+325	-325	Scalping Screen[3]
405071	1549	5-14-71	Air	15.6	0.0	0.0	3.8	12.0	84.2	100
405075	1549	5-14-71	Air	45.0	5.8	31.4	35.4	16.2	11.2	24
404661	1527	3-25-71	Air	16.0	0.0	0.0	5.4	12.0	82.6	100
404662	1527	3-24-71	Air	46.0	8.0	33.6	34.2	12.2	12.0	24
404663	1526	3-23-71	Air	15.3	0.0	0.0	4.0	8.0	88.0	100
404664	1526	3-23-71	Air	46.0	7.2	33.0	35.8	14.0	10.0	24

Notes:
1. Average particle diameter from Fisher Sub-Sieve Sizer.
2. U.S. Standard Screens.
3. Tyler Series Screens.
4. Off Scale - Estimated.

WSC/lmk
8/4/72

Table 21

COMPACTING, PREHEATING AND EXTRUDING CONDITIONS FOR EFFECT OF INCREASING HOT DEFORMATION ON FRACTURE TOUGHNESS

Sample No.	Atomizing Gas	Powder Size[1] µM	Cold Compact Press.[2] ksi	Green Density[3] %	Preheat Method[4]	Preheat Time @ 1000 F	Hot Compact Press.[5] ksi	Press. Dwell Min.	Extrusion Cylinder Temp. °F	Section[6] dia.	Extrusion Breakout Press. ksi	Extrusion Speed ft/min	Extrusion No.
Al-6.5 Zn-2.3 Mg-1.5 Cu													
405071A-2	Air	15.6	38	82.1	CANAR	1.7 hrs.	90	1	700	2.0"	56.3	3	6202
405071A-3	Air	15.6	38	82.7	CANAR	2.7 hrs.	90	1	700	.88"	80.6	3	6213
405075-2	Air	45.0	38	82.6	CANAR	1.9 hrs.	90	1	700	2.0"	63.8	3	6209
405075-3	Air	45.0	38	82.3	CANAR	2.3 hrs.	90	1	700	.88"	78.7	3	6206
Al-5.9 Zn-2.1 Mg-2.2 Cu-0.11 Zr													
404661-1	Air	16.0	40	(7)	CANAR	2.0 hrs.	90	1	700	2.0"	56.3	3	6187
404661-2	Air	16.0	40	(7)	CANAR	2.1 hrs.	90	1	700	2.0"	54.5	3	6188
404661-3	Air	16.0	40	(7)	CANAR	2.7 hrs.	90	1	700	.88"	93.8	3	6197
404662-1	Air	46.0	40	(7)	CANAR	2.6 hrs.	90	1	700	2.0"	61.9	3	6189
404662-2	Air	46.0	40	(7)	CANAR	2.8 hrs.	90	1	700	2.0"	63.8	3	6190
404662-3	Air	46.0	40	(7)	CANAR	3.0 hrs.	90	1	700	.88"	90.0	3	6198
Al-9.2 Zn-2.5 Mg-1.0 Cu													
404663-1	Air	15.3	40	(7)	CANAR	3.0 hrs.	90	1	700	2.0"	54.5	3	6191
404663-2	Air	15.3	40	(7)	CANAR	3.2 hrs.	90	1	700	2.0"	52.5	3	6192
404663-3	Air	15.3	40	(7)	CANAR	3.5 hrs.	90	1	700	.88"	78.7	3	6199
404664-1	Air	46.0	40	(7)	CANAR	2.0 hrs.	90	1	700	2.0"	52.5	3	6195
404664-2	Air	46.0	40	(7)	CANAR	2.5 hrs.	90	1	700	2.0"	52.5	3	6196
404664-3	Air	46.0	40	(7)	CANAR	3.7 hrs.	90	1	700	.88"	75.0	3	6200

Notes:
1. Average Particle Diameter.
2. Compacts prepared by Wet Bag Isostatic Pressing.
3. Percent of Theoretical Density.
4. Can preheated with flowing argon, can and compact hot pressed.
5. Pressed in extrusion cylinder at ram face pressures shown.
6. 2" dia. (Extrusion Ratio = 9.3:1). 7/8" dia. (Extrusion Ratio = 53:1).
7. Not measured.

WSC:slo
9/29/72

Table 22

LONGITUDINAL TENSILE AND NOTCHED TENSILE PROPERTIES OF Al-6.5 Zn-2.3 Mg-1.5 Cu ALLOY EXTRUSIONS

Sample No.	Powder Size[3] µM	Preheat Method	Extrusion Ratio	Second-Step Age @ 325 F	T.S. ksi	Y.S. ksi	% El. in 4D	NTS/YS	Purity % Si	Purity % Fe
405071-2B	15.6	CANAR	9.3	None	88.8	83.9	13.0	1.27	.005	.005
405071-2C	15.6	CANAR	9.3	13 hrs.	80.4	74.6	15.0	1.30	.005	.005
405071-3B	15.6	CANAR	53	None	88.7	83.3	12.0	1.29	.005	.005
405071-3C	15.6	CANAR	53	13 hrs.	79.4	74.1	16.0	1.30	.005	.005
405075-2B	45.0	CANAR	9.3	None	87.0	83.0	14.0	1.20	.00	.00
405075-2C	45.0	CANAR	9.3	13 hrs.	83.2	78.4	14.0	1.29	.00	.00
405075-3B	45.0	CANAR	53	None	90.7	85.6	12.0	1.27	.00	.00
405075-3C	45.0	CANAR	53	13 hrs.	85.5	81.2	14.0	1.21	.00	.00

Notes:
1. All compacts preheated using a flowing argon atmosphere.
2. Samples from 405071 and 405075 solution heat treated as 0.75" diameter rod. Solution heat treated 2 hours @ 920 F, CWQ, no natural age, first-step aged 24 hours @ 250 F.
3. Average Particle Diameter.
4. Mechanical Testing J.O. 051071-D.

WSC/lmk
8/10/72

Table 23

LONGITUDINAL TENSILE AND NOTCHED TENSILE PROPERTIES OF
Al-5.9 Zn-2.1 Mg-2.3 Cu-0.1 Zr ALLOY EXTRUSIONS

Sample No.	Powder Size[3] μM	Preheat Method	Extrusion Ratio	Second-Step Age @ 325 F	T.S. ksi	Y.S. ksi	% El. in 4D	NTS/YS	Purity % Si	Purity % Fe
404661-2B	16.0	CANAR	9.3	8 hrs.	84.0	78.4	14.0	1.40	.00	.00
404661-2C	16.0	CANAR	9.3	16 hrs.	77.0	69.6	14.0	1.35	.00	.00
404661-3B	16.0	CANAR	53	8 hrs.	83.8	78.3	14.0	1.37	.00	.00
404661-3C	16.0	CANAR	53	16 hrs.	77.6	70.7	15.0	1.34	.00	.00
404662-2B	46.0	CANAR	9.3	8 hrs.	89.5	85.2	12.0	1.16	.00	.00
404662-2C	46.0	CANAR	9.3	16 hrs.	84.4	79.1	14.0	1.30	.00	.00
404662-3B	46.0	CANAR	53	8 hrs.	89.7	85.4	12.0	1.15	.00	.00
404662-3C	46.0	CANAR	53	16 hrs.	84.0	78.9	14.0	1.28	.00	.00

Notes:
1. All compacts preheated using a flowing argon atmosphere.
2. Samples from 404661 and 404662 solution heat treated as 0.75" diameter rod, solution heat treated 2 hours @ 890 F, CWQ, no natural age, first-step aged 24 hours @ 250 F.
3. Average Particle Diameter.
4. Mechanical Testing J.O. 051071-D.

WSC/lmk
8/10/72

Table 24

LONGITUDINAL TENSILE AND NOTCHED TENSILE PROPERTIES OF Al-9.0 Zn-2.5 Mg-1.0 Cu EXTRUSIONS

Sample No.	Powder Size[3] μM	Preheat Method	Extrusion Ratio	Second-Step Age @ 325 F	T.S. ksi	Y.S. ksi	% El. in 4D	NTS/YS	Purity % Si	Purity % Fe
404663-2A	15.3	CANAR	9.3	None	99.2	92.7	8.0	1.11	.00	.00
404663-2B	15.3	CANAR	9.3	6 hrs.	86.2	83.0	13.0	1.22	.00	.00
404663-2C	15.3	CANAR	9.3	16 hrs.	79.8	75.3	7.0	1.27	.00	.00
404663-3A	15.3	CANAR	53	None	100.4	95.4	11.0	1.19	.00	.00
404663-3B	15.3	CANAR	53	6 hrs.					.00	.00
404663-3C	15.3	CANAR	53	16 hrs.	78.4	73.8	8.0	1.30	.00	.00
404664-2A	46.0	CANAR	9.3	None	97.0	93.5	12.0	.92	.00	.00
404664-2B	46.0	CANAR	9.3	6 hrs.	88.8	87.1	10.0	1.00	.00	.00
404664-2C	46.0	CANAR	9.3	16 hrs.	83.9	80.8	14.0	1.21	.00	.00
404664-3A	46.0	CANAR	53	None	95.4	91.7	12.0	.97	.00	.00
404664-3B	46.0	CANAR	53	6 hrs.	87.0	85.4	10.0	1.09	.00	.00
404664-3C	46.0	CANAR	53	16 hrs.	80.6	77.8	12.0	1.18	.00	.00

Notes:
1. All compacts preheated using a flowing argon atmosphere.
2. Samples from 404663 and 404664 solution heat treated as 0.75" diameter rod. Solution heat treated 2 hours @ 880 F, CWQ, no natural age, first-step aged 24 hours @ 250 F.
3. Average Particle Diameter.
4. Mechanical Testing J.O. 051071-D.

WSC/lmk
8/10/72

Table 25

EFFECT OF EXTRUSION RATIO ON LONGITUDINAL STRENGTH, DUCTILITY AND FRACTURE TOUGHNESS OF P/M EXTRUSIONS

Powder Size[1] µM	Second-Step Age[2] @ 325 F	Yield Strength - ksi, Extrusion Ratio 9.3	Yield Strength - ksi, Extrusion Ratio 53	% Elongation, Extrusion Ratio 9.3	% Elongation, Extrusion Ratio 53	NTS/YS, Extrusion Ratio 9.3	NTS/YS, Extrusion Ratio 53
Al-6.5 Zn-2.3 Mg-1.5 Cu							
15.6	None	83.9	83.3	13.0	12.0	1.27	1.29
45.0	None	83.0	85.6	14.0	12.0	1.20	1.27
15.6	13 hrs.	74.6	74.1	15.0	16.0	1.30	1.30
45.0	13 hrs.	78.4	81.2	14.0	14.0	1.29	1.21
Al-5.9 Zn-2.1 Mg-2.3 Cu-0.1 Zr							
16.0	8 hrs.	78.4	78.3	14.0	14.0	1.40	1.37
46.0	8 hrs.	85.2	85.4	12.0	12.0	1.16	1.15
16.0	16 hrs.	69.6	70.7	14.0	15.0	1.35	1.34
46.0	16 hrs.	79.1	78.9	14.0	14.0	1.30	1.28
Al-9.2 Zn-2.5 Mg-1.0 Cu							
15.3	None	92.7	95.4	8.0	11.0	1.11	1.19
46.0	None	93.5	91.7	12.0	12.0	.92	.97
15.3	6 hrs.	83.0	(3)	13.0	(3)	1.22	(3)
46.0	6 hrs.	87.1	85.4	10.0	10.0	1.00	1.09
15.3	16 hrs.	75.3	73.8	7.0	8.0	1.27	1.30
46.0	16 hrs.	80.8	77.8	14.0	12.0	1.21	1.18

Notes:
1. Average particle diameter.
2. First step aged 24 hours at 250 F.
3. No tests.

WSC/lmk
8/15/72

Table 26

FABRICATING CONDITIONS OF EXTRUSIONS FOR DETERMINING THE EFFECT OF REDUCED Fe AND Si EXTRUSION FRACTURE TOUGHNESS

Sample No.	Powder Size[1] µM	Cold Compact Pressure ksi	Green Density %	Preheat Method[3]	Preheat Time @ [illegible]00 F	Hot Compact Press.[4] ksi	Extrusion Cylinder Temp. °F	Section[5]	Extrusion Ratio	Extrusion Breakout Pressure ksi	Extrusion No.
Al-6.55 Zn-2.39 Mg-1.50 Cu-0.04 Fe-0.04 Si (from Ref. 5)											
398749-1	16.5	35	82	FCE	2.2	90	700	OCTA.	17.1	54.3	4669
398749-2	16.5	35	83	FCE	2.9	90	700	OCTA.	17.1	57.0	4670
398749-3	16.5	35	85	FCE	3.1	90	700	OCTA.	17.1	(6)	4671
Al-6.49 Zn-2.21 Mg-1.52 Cu-0.005 Fe-0.005 Si-0.002 Be											
405071A-4	15.6	60	87.4	FCE	2.3	90	700	2.0"	9.3	56.3	6193
Al-7.92 Zn-2.56 Mg-1.09 Cu-0.04 Fe-0.05 Si-0.003 Be											
404880-E3BD	16.5	30	78[7]	FCE	1.2	90[7]	700	OCTA.	17.1	77.4	6171
Al-8.19 Zn-2.52 Mg-1.03 Cu-0.01 Fe-0.01 Si-0.002 Be											
405481-E7BD	13.6	30	77[7]	FCE	2.0	90[7]	700	OCTA.	17.1	68.6	6629

Notes:
1. Average particle diameter from Fisher Sub Sieve Sizer.
2. Percent of theoretical density. 398749 (37 lb. compacts), 405071A-4 20 lb. compact.
3. Compacts preheated in flowing argon in an atmosphere (muffle) furnace.
4. Ram face pressure in an extrusion cylinder, except see footnote 7.
5. 1-9/16" octagon shown in Figure 1.
6. Not determined.
7. 170 lb. compacts hot pressed after preheat in tapered hot compacting cylinder. Blind die end billet scalped, reheated and extruded.

WSC/lmk

Table 27

EFFECT OF REDUCED Fe AND Si ON MECHANICAL PROPERTIES OF P/M EXTRUSIONS

Sample No.	Purity[1] % Fe	Purity[1] % Si	Second-Step Age[2] @ 325 F	T.S. ksi	Y.S. ksi	% El. in 4D	NTS/YS	T.S. ksi	Y.S. ksi	% El. in 4D	NTS/YS
Al-6.5 Zn-2.3 Mg-1.5 Cu											
398749-1	.04	.04	2 hrs.[4]	89.8	84.8	13.5	1.28	79.5	72.8	8.0	.72
398749-4	.04	.04	13 hrs.[4]	80.8	75.0	13.5	1.27	73.4	65.9	8.0	.83
405071A-4B	.005	.005	None	90.0	81.8	12.0	1.39	79.9	68.4	9.0	.89
Al-8.0 Zn-2.5 Mg-1.0 Cu											
404880-E3B	.04	.05	None[3]	98.3	94.3	8.0	1.25	86.1	78.7	9.4	.66
404880-E3C	.04	.05	6 hrs.	87.2	84.2	11.2	1.28	80.1	74.2	9.4	.66
405481-E7C	.01	.01	None	97.3	92.6	8.0	1.27	86.0	76.8	11.7	.78

Notes:
1. Higher purity is indicated by reduced Fe and Si.
2. All extrusions solution heat treated 2 hours @ 920 F, CWQ, naturally aged 4-7 days + 24 hours @ 250 F.
3. Extrusion heated to 325 F with no hold @ 325 F.
4. Data from Ref. 5.

WSC/lmk
8/11/72

Table 28

COMPOSITION AND POWDER SIZE OF Cu-FREE P/M Al-Zn-Mg ALLOYS. DATA FROM Cu-BEARING COMPARISON ALLOYS FROM REF. 5.

Sample No.	Pot No.	Powder Size µM[1]	Composition[2] - Weight %							
			Si	Fe	Cu	Mg	Zn	Co	Ni	Be
399604	1533	15.9	.06	.04	0.00	2.47	9.31	.00	.00	.002
399605	1533	46.0	.06	.04	0.00	2.48	9.35	.00	.00	.002
398761	1462	16.9	.04	.04	1.10	2.59	8.94	.00	.00	.000
399606	1534	15.0	.05	.05	0.00	2.42	9.23	.81	.01	.002
399607	1534	45.0	.05	.05	0.00	2.46	9.29	.81	.01	.002
398763	1464	14.8	.04	.05	1.04	2.56	8.80	.80	.01	.000

Notes: 1. Average Particle Diameter.
2. Mn=Cr=Ti=Zr=0.00.

Sample No.	Pot No.	Date Atomized	Powder Size µM[1]	Screen Analysis[2] - Weight %					Scalping Screen[3]
				-30+50	-50+100	-100+200	-200+325	-325	
399604	1533	4-1-71	15.9	0.0	0.0	5.6	12.6	81.8	100
399605	1533	4-1-71	46.0	11.4	36.4	31.2	12.5	8.5	24
398761	1462	10-2-70	16.9	0.0	0.0	10.0	16.6	73.4	100
399606	1534	4-2-71	15.0	0.0	0.0	4.6	9.6	85.8	100
399607	1534	4-2-71	45.0	6.8	33.2	35.8	15.2	9.0	24
398763	1464	10-5-70	14.8	0.0	0.0	5.0	11.0	84.0	100

Notes: 1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. U.S. Standard Screens.
3. Tyler Series Screens.

WSC:km
8-7-72

Table 29

FABRICATING CONDITIONS FOR Cu-FREE P/M Al-Zn-Mn ALLOY EXTRUSIONS

Sample No.	Powder Size[1] μM	Cold Compact Press.[2] ksi	Green Density[3] %	Preheat Method[4]	Preheat Time @ 1000 F	Hot Compact Press.[5] ksi	Press. Dwell Min.	Extrusion Cylinder Temp. °F	Section[6]	Extrusion Breakout Press. ksi	Extrusion Speed ft/min.	Extrusion No.
Al-9.3 Zn-2.5 Mg												
399604-1	15.9	30	(7)	FCE	3.5 hrs.	90	1	700	Octa.	53.4	3	5780
399604-2	15.9	30	(7)	FCE	4.0	90	1	700	Octa.	61.1	3	5781
399604-3	15.9	30	(7)	FCE	4.2	90	1	700	Octa.	57.0	3	5782
399605-1	46.0	30	(7)	FCE	4.4	90	1	700	Octa.	66.5	3	5783
399605-2	46.0	30	(7)	FCE	4.6	90	1	700	Octa.	63.8	3	5784
399605-3	46.0	30	(7)	FCE	4.8	90	1	700	Octa.	62.5	3	5785
Al-8.9 Zn-2.6 Mg-1.1 Cu[8]												
398761-1	16.9	35	82	FCE	3.5	90	1	700	Octa.	54.3	3	4705
398761-3	16.9	35	81	FCE	3.5	90	1	700	Octa.	54.3	3	4706
398761-4	16.9	35	79	FCE	3.9	90	1	700	Octa.	51.6	3	4707
Al-9.3-Zn-2.4 Mg-0.8 Co												
399606-1	15.0	30	(7)	FCE	2.5	90	1	700	Octa.	55.7	3	5775
399606-2	15.0	30	(7)	FCE	2.7	90	1	700	Octa.	53.0	3	5776
399606-3	15.0	30	(7)	FCE	2.8	90	1	700	Octa.	54.3	3	5777
399607-1	45.0	30	(7)	FCE	3.0	90	1	700	Octa.	62.5	3	5778
399607-2	45.0	30	(7)	FCE	3.2	90	1	700	Octa.	62.5	3	5779
Al-8.8 Zn-2.6 Mg-1.0 Cu-0.8 Co[8]												
398763-1	14.8	35	79	FCE	1.3	90	1	700	Octa.	46.2	3	4712
398763-2	14.8	35	79	FCE	1.5	90	1	700	Octa.	46.2	3	4713
398763-3	14.8	35	79	FCE	1.7	90	1	700	Octa.	46.2	3	4714

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Compacts prepared by Wet Bag Isostatic Compact.
3. Percent of Theoretical Density.
4. Green compacts preheated in flowing argon at 0.29 CFH/lb. compact to 1000 F in an atmosphere (muffle) furnace.
5. All compacts hot pressed in extrusion cylinders at ram face pressures shown.
6. 17.1:1 Extrusion Ratio - see Figure 1 for section drawing.
7. Not measured.
8. Fabricating conditions for comparison Cu-bearing extrusions from Ref. 5.

WSC:slo
9/29/72

Table 30

TENSILE AND NOTCHED TENSILE PROPERTIES OF Cu-FREE P/M 7XXX ALLOY EXTRUSIONS

Sample No.	Powder Size μM	Quench[4] °F/sec	Second-Step Age[3] @ 300 F	Longitudinal T.S. ksi	Longitudinal Y.S. ksi	Longitudinal % El. in 4D	Longitudinal NTS/YS	Transverse T.S. ksi	Transverse Y.S. ksi	Transverse % El. in 4D	Transverse NTS/YS
Al-9.3 Zn-2.5 Mg											
399604-1D	15.9	160	None	91.3	91.1	7	1.00	84.6	80.7	4	.59
399604-1B	15.9	160	6 hrs.	86.4	85.4	11	1.15	79.2	73.0	6.5	.51
399604-1C	15.9	160	18 hrs.	79.7	77.6[1]	14[1]	1.32	73.4	68.5	10	.83
399604-3D	15.9	3	None	65.8	56.0	14	1.74	58.9	49.2	9	.91
399604-3B	15.9	3	6 hrs.	65.0	56.7	14	1.62	60.4	50.4	8	.75
399605-1D	46.0	160	None	91.8	90.7	8	.77	84.5	82.1	2	.41
399605-1B	46.0	160	6 hrs.	88.8	87.8	8	.81	82.2	78.2	1.5	.45
399605-1C	46.0	160	18 hrs.	82.5	80.5	13	1.20	76.4	72.8	5	.44
399605-3D	46.0	3	None	78.5	73.6	9	.92	75.8	69.1	2	.42
399605-3B	46.0	3	6 hrs.	79.3	74.4	8	.94	71.7	67.0	2	.49
Al-8.9 Zn-2.6 Mg-1.1 Cu											
398761-A1	16.9	160	None	96.4	92.6	10	.97	89.5	78.0	7	.67
398761-A2	16.9	160	6 hrs.	79.4	75.2	13	1.19	78.8	73.0	4[2]	.68
398761-A3	16.9	160	16 hrs.	71.7	65.5	15	1.36	73.7	67.5	5	.66
398761-B1	16.9	3	None	71.7	59.4	14	1.45	65.1	52.8	5	.57
398761-B2	16.9	3	6 hrs.	63.8	54.4	12	1.35	62.4	49.8	8	.81
Al-9.2 Zn-2.4 Mg-0.81 Co											
399606-1D	15.0	160	None	89.6	88.2	10[1]	1.14	89.2	81.0	4	.47
399606-1B	15.0	160	6 hrs.	85.8	84.6	12	1.17	80.0	74.5	6	.64
399606-1C	15.0	160	18 hrs.	79.7	77.6	12	1.28	73.5	68.6	9	.73
399606-3D	15.0	3	None	57.0	53.7	2[2]	1.47	57.2	48.8	9	.92
399606-3B	15.0	3	6 hrs.	62.6	54.7	14	1.43	58.1	49.8	6	.81
399607-1A3	45.0	160	None	99.6	99.0	8	.70	86.4	83.4	2	.35
399607-1A1	45.0	160	6 hrs.	94.5	92.4	14	.86	85.1	77.6	4	.48
399607-1A2	45.0	160	18 hrs.	85.1	83.6	16	1.29	77.4	72.6	4	.53
399607-2A3	45.0	3	None	84.0	78.6	10[1]	.83	72.6	67.6	2[1,2]	.32
399607-2A1	45.0	3	6 hrs.	79.2	72.6	10	1.01	68.9	65.1[1]	2[1]	.34
Al-8.8 Zn-2.6 Mg-1.0 Cu-0.80 Co											
398763-A1	14.8	160	None	100.8	95.9	10	.75	90.0	81.4	8	.50
398763-A2	14.8	160	6 hrs.	87.6	83.9	14	1.00	82.1	76.4	10	.57
398763-A3	14.8	160	16 hrs.	81.4	75.9	16	1.13	75.6	67.9	10	.69
398763-B1	14.8	3	None	63.8	50.8	14	1.35	57.9	46.3	12	.98
398763-B2	14.8	3	6 hrs.	57.4	48.0	15	1.43	53.5	44.3	12	1.07

Notes:
1. Single specimen, all others average of duplicate specimens.
2. Failed outside of gauge length.
3. 399604-399607 first-stop aged 48 hrs. @ 250 F, second-step aged @ 300 F. 398761 and 398763 first-step aged 24 hrs. @ 250 F, second-step aged @ 325 F.
4. Quench rate from solution heat treat temperature - Rate from 750 F to 550 F.

WSC/lmk
8/15/72

Table 31

STRESS-CORROSION CRACKING PERFORMANCE OF P/M Al-9.0 Zn-2.5 Mg ALLOY EXTRUSIONS

Sample No.	Cu	Co	Powder Size μM[1]	LYS ksi	TYS ksi	Days to Failure at Applied Stress[3]: A.I. Test[2] 42 ksi	A.I. Test[2] 25 ksi	New Kensington Atmosphere 42 ksi	New Kensington Atmosphere 35 ksi	New Kensington Atmosphere 25 ksi
399604-1B	None	None	15.9	85.4	73.0	2,2	7,51	32,39,40	27,27	40,135,ok200
399605-1B	None	None	46.0	87.8	78.2	1,2	3,12	12,12	12,20	27,27,27
399606-1B	None	.8%	15.0	84.6	74.5	5,6	13,16	27,55,70	59,66	48,107,158
399607-1A2	None	.8%	45.0	83.6	72.6	3,5	14,15	32,107,116	88,107	152,167,ok200
398761-A1	1%	None	16.9	92.6	78.0	10,11	28,33	3ok200	2ok200	3ok200
398763-A2	1%	.8%	14.8	83.9	76.4	28,46	2ok84	3ok200	2ok200	3ok200

Notes:
1. Average Particle Diameter.
2. 3.5% NaCl solution per Federal Test Method 823.
3. Transverse 1/8" diameter tensile bars.

WSC:km
8-3-72

Table 32

COMPOSITION AND POWDER SIZE OF FINE AND COARSE ALLOY POWDERS FOR IMPROVING FRACTURE TOUGHNESS BY DECREASING OXIDES FROM POWDER SURFACES

Sample No.	Pot No.	Powder Size[1] µM	Composition[2] - Weight % Si	Fe	Cu	Mg	Zn	Be	Oxygen[3]
405071	1549	15.6	.005	.005	1.52	2.21	6.49	.002	.355
405075	1549	45.0	.00	.00	1.52	2.25	6.49	.002	.096

Notes: 1. Average Particle Diameter.
2. Melt Analysis - Mn=Cr=Ti=Zr=Co=Ni=0.00.
3. Fast Neutron Activation Analysis on Powder.

Sample No.	Pot No.	Date Atomized	Powder Size[1] µM	Screen Analysis[2]-Weight % -30+50	-50+100	-100+200	-200+325	-325	Scalping Screen[3]
405071	1549	5-14-71	15.6	0.0	0.0	3.8	12.0	84.2	100
405075	1549	5-14-71	45.0	5.8	31.4	35.4	16.2	11.2	24

Notes: 1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. U.S. Standard Screens.
3. Tyler Series Screens.

WSC:km
8-4-72

Table 33

FABRICATING CONDITIONS FOR EXTRUSIONS FOR IMPROVING FRACTURE TOUGHNESS BY REDUCED OXIDES FROM INCREASED POWDER SIZE

Sample No.	Powder Size[1] μM	Cold Compact Pressure[2] ksi	Green Density[3] %	Preheat Method[4]	Preheat Time 1000 F	Hot Compact Pressure[5] ksi	Extrusion Cylinder Temp °F	Section[6] dia.	Extrusion Breakout Pressure ksi	Extrusion No.
405071-1	15.6	60	88.4	CANAR	1.7 hrs	90	700	2.0"	(7)	6201
405071-4	15.6	60	87.4	FCE	2.3 hrs	90	700	2.0"	56.3	6193
405075-1	45.0	60	86.8	CANAR	2.5 hrs	90	700	2.0"	65.7	6214
405075-4	45.0	60	87.0	FCE	1.9 hrs	90	700	2.0"	65.7	6207

Notes:
1. Average Particle Diameter.
2. Compacts prepared by a Wet Bag Isostatic Pressing Technique.
3. Percent of theoretical.
4. CANAR - can preheat/hot press with flowing argon.
   FCE - atmosphere furnace preheat with flowing argon, bare compact hot pressed in extrusion cylinder.
5. Bare compacts or compacts in cans hot pressed in 6-3/8" extrusion cylinder.
6. 9.3:1 Extrusion Ratio-extruded at 3 feet/minute.
7. Not determined.

WSC:dk
8-16-72

Table 34

EFFECT OF POWDER SIZE ON EXTRUSION PROPERTIES FOR FURNACE AND CAN PREHEATS

Sample No.	Powder Size[1] μM	Preheat Method[2]	Extrusion Oxygen[3] Wt.%	Extrusion Density[4]	Second-Step Age[5] @ 325 F	Longitudinal T.S. ksi	Longitudinal Y.S. ksi	Longitudinal % El in 4D	Longitudinal NTS/YS	Transverse T.S. ksi	Transverse Y.S. ksi	Transverse % El in 4D	Transverse NTS/YS
405071-4B	15.6	FCE	.368	.1020	None	90.0	81.8	12.0	1.39	79.9	68.4	9.0	0.89
405075-4B	45.0	FCE	.086	.1015	None	88.7	82.8	14.0	1.30	71.9	69.8	2.0	0.53
405071-1B	15.6	CANAR	.295	.1019	None	90.1	82.4	12.7	1.27	78.4	68.4	7.0	0.60
405075-1B	45.0	CANAR	.081	.1007	None	88.9	82.4	13.2	1.21	71.4	67.6	2.0	0.51
405071-1C	15.6	CANAR	.295	.1019	13 hrs	81.4	75.6	16.0	1.41	75.9	69.0	6.0	0.59
405075-1C	45.0	CANAR	.081	.1007	13 hrs	83.8	79.1	13.0	1.24	68.9	65.9	2.0	0.46

Notes:
1. Average Particle Diameter.
2. See Table 33, Footnote 4.
3. Fast Neutron Activation Analysis of Extrusions.
4. Density in as-quenched temper (lbs./cu. in.).
5. Extrusion solution heat treated for 2 hours @ 920 F, cold water quenched, aged 7 days at room temperature + 24 hours @ 250 F.

WSC:km
8-7-72

Table 35

COMPOSITION OF ALLOYS ATOMIZED WITH INERT GASES TO REDUCE THE AMOUNT OF OXIDE SECOND PHASE PARTICLES

Sample No.	Pot No.	Powder Size[2] μM	Atomizing Gas	Composition[1] - Weight %									
				Si	Fe	Cu	Mg	Zn	Zr	Co	Ni	Be	O_2[3]
405071	1549	15.6	Air	.005	.005	1.52	2.21	6.49	.00	.00	.00	.002	.355
405075	1549	45.0	Air	.00	.00	1.52	2.25	6.49	.00	.00	.00	.002	.096
405073	1549	15.8	Nitrogen	.007	.004	1.49	2.25	6.47	.00	.00	.00	.002	
405077	1549	52.0[4]	Nitrogen	.007	.004	1.53	2.30	6.46	.00	.00	.00	.002	
405072	1550	20.0	Argon	.004	.004	1.52	2.25	6.38	.00	.00	.00	.002	.195
405076	1550	50.0	Argon	.003	.004	1.54	2.26	6.41	.00	.00	.00	.002	.074
405074	1550	14.5	Helium	.004	.005	1.56	2.30	6.49	.00	.00	.00	.002	
405078	1550	51.0[4]	Helium	.003	.004	1.52	2.26	6.40	.00	.00	.00	.002	

Notes:
1. Mn=Cr=Ti=0.00
2. Average Particle Diameter from Fisher Sub-Sieve Sizer.
3. Fast Neutron Activiation Analysis on Powder
4. Off scale - estimated.

WSC:ds
9/29/72

Table 36

POWDER SIZE AND SCREEN ANALYSES OF ALLOYS FOR INERT ATOMIZING TO REDUCE THE AMOUNT OF OXIDE SECOND PHASE PARTICLES

Sample No.	Pot No.	Date Atomized	Atomizing Gas	Powder Size[1] μM	Screen Analysis[2] - Weight %					Scalping Screen[3]
					-30+50	-50+100	-100+200	-200+325	-325	
405071	1549	5-14-71	Air	15.6	0.0	0.0	3.8	12.0	84.2	100
405075	1549	5-14-71	Air	45.0	5.8	31.4	35.4	16.2	11.2	24
405073	1549	5-14-71	Nitrogen	15.8	0.0	0.0	1.2	6.2	92.6	100
405077	1549	5-14-71	Nitrogen	52.0[4]	8.6	35.6	33.8	11.4	10.4	24
405072	1550	5-15-71	Argon	20.0	0.0	0.0	2.8	12.2	85.0	100
405076	1550	5-15-71	Argon	50.0	2.6	30.8	42.6	15.6	8.4	24
405074	1550	5-15-71	Helium	14.5	0.0	0.0	1.6	5.6	92.8	100
405078	1550	5-15-71	Helium	51.0[4]	12.0	37.2	30.2	8.4	12.4	24

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. U.S. Standard Screens.
3. Tyler Series Screens.
4. Off Scale - Estimated.

WSC/lmk
8/4/72

Table 37

FABRICATION CONDITIONS FOR EXTRUSION FROM INERT ATOMIZED POWDERS FOR REDUCED AMOUNTS OF OXIDE SECOND PHASE PARTICLES

Sample No.	Atomizing Gas	Powder Size[1] μM	Cold Compact Press.[2] ksi	Green Density[3] %	Preheat Method[4]	Preheat Time @ 1000 F	Hot Compact Press.[5] ksi	Press. Dwell Min.	Extrusion Cylinder Temp. °F	Section[6] dia.	Extrusion Breakout Press. ksi	Extrusion Speed ft/min	Extrusion No.
Al-6.5 Zn-2.3 Mg-1.5 Cu													
404071A	Air	15.6	0	44	None								
405071-1	Air	15.6	60	88.4	CANAR	1.7 hrs.	90	1	700	2.0"	(7)	3	6201
405071A-1	Air	15.6	60	87.4	FCE	2.3 hrs.	90	1	700	2.0"	56.3	3	6193
405075	Air	45.0	0	47	None								
405075-1	Air	45.0	60	86.8	CANAR	2.5 hrs.	90	1	700	2.0"	65.7	3	6214
405075-4	Air	45.0	60	87.0	FCE	1.9 hrs.	90	1	700	2.0"	65.7	3	6207
405072	Argon	20.0	0	50	None								
405072-3	Argon	20.0	30	80.5	None								
405072-2	Argon	20.0	45	85.7	None								
405072-1	Argon	20.0	60	86.5	CANAR	1.7 hrs.	90	1	700	2.0"	60.0	3	6203
405072-4	Argon	20.0	60	88.4	FCE	2.6 hrs.	90	1	700	2.0"	65.7	3	6194
405076	Argon	50	0	54	None								
405076-3	Argon	50	30	80.8	None								
405076-2	Argon	50	45	85.6	None								
405076-1	Argon	50	60	89.6	CANAR	2.1 hrs.	90	1	700	2.0"	63.8	3	6210
405076-4	Argon	50	60	88.2	FCE	2.1 hrs.	90	1	700	2.0"	65.7	3	6208
405073	Nitrogen	15.8	0	52	None								
405073-1	Nitrogen	15.8	60	86.5	CANAR	2.0 hrs.	90	1	700	2.0"	56.3	3	6204
405077	Nitrogen	52[8]	0	52	None								
405077-1	Nitrogen	52[8]	60	86.5	CANAR	2.2 hrs.	90	1	700	2.0"	63.8	3	6211
405074	Helium	14.5	0	53	None								
405074-1	Helium	14.5	60	88.7	CANAR	2.2 hrs.	90	1	700	2.0"	58.1	3	6205
405078	Helium	51[8]	0	54	None								
405078-1	Helium	51[8]	60	87.6	CANAR	2.4 hrs.	90	1	700	2.0"	67.5	3	6212

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Compacts prepared by Wet Bag Isostatic Compact.
3. Percent of Theoretical Density.
4. See Figure 25 for details of Preheat Method.
5. All compacts hot pressed in extrusion cylinders at ram face pressures shown.
6. Extruded from 6-3/8" diameter cylinder, except as noted. Extrusion Ratios: 2" dia. - 9.3; 7/8" dia. - 53; Octa. - 12.4
7. Not measured.
8. Off Scale - Estimated.

WSC:slo
9/29/72

Table 38

TENSILE AND NOTCHED TENSILE PROPERTIES OF EXTRUSIONS - LOW INSOLUBLE ELEMENT Al-6.5 Zn-2.3 Mg-1.5 Cu ALLOY

Sample No.	Atomizing Atmosphere	Powder Size[4] μM	MPD[5] (μ)	Preheat Method	Second-Step Age @ 325 F	Extrusion Oxygen[11] Wt. %	Extrusion Density[11] lbs/cu. in.	Longitudinal Properties[6] T.S. ksi	Longitudinal Y.S. ksi	Longitudinal % El. in 4D	Longitudinal NTS/YS	Transverse Properties T.S. ksi	Transverse Y.S. ksi	Transverse % El. in 4D	Transverse NTS/YS
405071-1B	Air	15.6	25	Canar	None	.295	.1019	90.1[7]	82.4[7]	12.7[7]	1.27[7]	78.4	68.4	7.0	0.60
405072-1B	Argon	20.0	27	Canar	None	.139	.1013	88.5[8]	81.2[9]	11.0[9]	1.19[7]	77.4	70.0	2.0[10]	0.54
405073-1B	Nitrogen	15.8	21	Canar	None	.140	(12)	92.2	85.6	12.8	1.03[7]	79.6	70.4	4.0[10]	0.47
405074-1B	Helium	14.5	19	Canar	None	.198	(12)	88.8[8]	83.8[9]	13.3[9]	1.25[7]	71.5[9]	68.8[9]	0[9,10]	0.57
405071-4B	Air	15.6	25	FCE	None	.368	.1020	90.0	81.8	12.0	1.39[7]	79.9	68.4	9.0	0.89
405072-4B	Argon	20.0	27	FCE	None	.148	.1016	91.9[8]	86.2[8]	11.5	1.32[7]	82.2	71.1	7.0[10]	0.64
405071-1C	Air	15.6	25	Canar	13 hrs.	.295	.1019	81.4	75.6	16.0	1.41	75.9	69.0	6.0	0.59
405072-1C	Argon	20.0	27	Canar	13 hrs.	.139	.1013	84.3[9]	78.5[9]	8.0[9]	1.13	79.2	73.2	6.0[10]	0.45
405073-1C	Nitrogen	15.8	21	Canar	13 hrs.	.140	(12)	81.2	78.2	3.0[10]	1.02	76.6	72.6	2.0[10]	0.53
405074-1C	Helium	14.5	19	Canar	13 hrs.	.198	(12)	83.8	78.8	16.0	1.33	71.4[9]	69.8[9]	0[9,10]	0.43
405075-1B	Air	45.0	117	Canar	None	.081	.1007	88.9[9]	82.4[8]	13.2[9]	1.21[7]	71.4	67.6	2.0	0.51
405076-1B	Argon	50.0	117	Canar	None	.050	.1007	84.3[7]	78.9[7]	11.1[7]	1.20[7]	70.9	67.8	3.0	0.52
405077-1B	Nitrogen	52[13]	122	Canar	None	.061	(12)	86.1[8]	79.4[9]	15.3[8]	1.20[7]	73.4	68.5	2.0	0.42
405078-1B	Helium	51[13]	130	Canar	None	.049	(12)	84.6[8]	77.9[9]	15.7[8]	1.22[7]	71.8[9]	68.2[9]	2.0[9]	0.52
405075-4B	Air	45.0	117	FCE	None	.066	.1015	88.7	82.8	14.0	1.30[7]	78.2	71.0	2.0	0.55
405076-4B	Argon	50.0	117	FCE	None	.062	.1014	86.2[8]	79.6[9]	15.8[8]	1.32[7]	71.9[9]	69.8[9]	2.0[9]	0.53
405075-1C	Air	45.0	117	Canar	13 hrs.	.081	.1007	83.8	79.1	13.0	1.24	68.9[9]	65.9[9]	2.0[9,10]	0.46
405076-1C	Argon	50.0	117	Canar	13 hrs.	.050	.1007	80.6[8]	77.1[9]	4.0[8,10]	1.26	73.9[9]	72.9[9]	0[9]	0.39
405077-1C	Nitrogen	52[13]	122	Canar	13 hrs.	.061	(12)	81.8[8]	78.0[9]	16.0[9]	1.17	73.4	71.8	2.0	0.41
405078-1C	Helium	51[13]	130	Canar	13 hrs.	.049	(12)	81.5[9]	78.0[9]	14.0[8]	1.19	73.8	71.8	2.0	0.41

Notes:
1. 9.3:1 extrusion ratio.
2. Mechanical Testing J. O. 051071-E.
3. All Extrusions solution heat treated 2 hours @ 920 F, CWQ, naturally aged 7 days, first-step artificially aged 24 hours @ 250 F.
4. Average Particle Diameter from Fisher Sub-Sieve Sizer.
5. Mean Particle Diameter = Particle size with 50% by weight above and below that size.
6. All values are average of duplicate specimens except where noted.
7. Average of four specimens. NTS/YS with 4 notched tensile specimens.
8. Average of three specimens.
9. Single test value.
10. Failed outside of gauge length.
11. Specimens in as quenched temper.
12. Not measured.
13. Off scale - estimated.

TABLE 39

EFFECT OF POWDER SIZE AND SHAPE ON DENSITY AND TRANSVERSE ELONGATION AND NTS/YS

Preheat	Particle Shape[3]	Elongation - %		NTS/YS		Density-lb/cu.in.	
		Fine[1]	Coarse[2]	Fine[1]	Coarse[2]	Fine[1]	Coarse[2]
FCE	Irregular	9	2	0.89	0.55	0.1020	0.1015
FCE	Regular	7	2	0.64	0.53	0.1016	0.1014
CANAR	Irregular	7	2	0.60	0.51	0.1019	0.1007
CANAR	Regular	2	3	0.54	0.52	0.1013	0.1007

Notes:
1. 15 μM APD.
2. 50 μM APD.
3. Irregular powders are air atomized. Regular powders are argon atomized.

WSC:km
8-4-72

Table 40

EFFECT OF CAN-ARGON PREHEATING ON EXTRUSION PROPERTIES
COMPARED TO ATMOSPHERE FURNACE PROPERTIES (FROM TABLE 39)

Atomizing Gas	Powder Size μM	Extrusion Oxygen Preheat wt.%		Extrusion Density Preheat lbs/cu.in.		Long. NTS/YS[3] Preheat		Trans. NTS/YS[3] Preheat	
		CANAR	FCE	CANAR	FCE	CANAR	FCE	CANAR	FCE
Air	15.6	.295	.368	.1019	.1020	1.27	1.39	.60	.89
Argon	20.0	.139	.148	.1013	.1016	1.19	1.32	.54	.64
Air	45.0	.081	.086	.1007	.1015	1.21	1.30	.51	.55
Argon	50.0	.050	.062	.1007	.1014	1.20	1.32	.52	.53

Notes: 1. Average Particle Diameter.
2. Density in as-quenched temper.
3. Extrusions aged 24 hours @ 250 F (from Table 38).

WSC:km
8-4-72

Table 41

COMPOSITION AND POWDER SIZE OF ALLOY - POWDERS FOR VACUUM PREHEATING TO IMPROVE FRACTURE TOUGHNESS

Sample No.	Pot No.	Powder Size µM	Atomizing Gas	Composition[1] - Weight % Si	Fe	Cu	Mg	Zn	Be
404877	1537	15.6	Air	.06	.05	1.53	2.26	6.46	.002
405073	1549	15.8	Nitrogen	.007	.004	1.49	2.25	6.47	.002
405536	1567	14.0	Air	.02	.01	1.06	2.41	7.82	.002
405481	1566	13.6	Air	.01	.01	1.03	2.52	8.19	.002
404882	1542	49.3	Air	.05	.04	1.06	2.56	8.34	.003

Notes: 1. Mn=Cr=Ti=Ni=Zr=0.00.
2. Average Particle Diameter.

Sample No.	Pot No.	Date Atomized	Atomizing Gas	Powder Size µM	Screen Analysis[2] - Weight% -30+50	-50+100	-100+200	-200+325	-325	Scalping Screen[3]
404877	1537	4-14-71	Air	15.6	0.0	0.0	4.6	11.8	83.6	100
405073	1549	5-14-71	Nitrogen	15.8	0.0	0.0	1.2	6.2	92.6	100
405536	1567	9-8-71	Air	14.0	0.0	0.0	1.0	5.5	93.5	100
405481	1566	8-13-71	Air	13.6	0.0	0.0	1.2	7.3	91.5	100
404882	1542	4-23-71	Air	49.3	13.0	34.6	29.3	13.2	9.9	24

Notes: 1. Average Particle Daimeter from Fisher Sub-Sieve Sizer.
2. U.S. Standard Screens.
3. Tyler Series Screens.

WSC:km
8-7-72

Table 42

P/M EXTRUSION FABRICATING CONDITIONS WITH VACUUM PREHEATING
FOR IMPROVED FRACTURE TOUGHNESS

Sample No.	Atomizing Gas	Powder Size[1] μM	Cold Compact Press.[2] ksi	Green Density[3] %	Preheat Method[4]	Preheat Time @ 1000 F	Hot Compact Press.[5] ksi	Press. Dwell ksi	Extrusion Cylinder Temp. °F	Section[6]	Extrusion Breakout Press. ksi	Extrusion Speed ft/min.	Extrusion No.
Al-6.5 Zn-2.3 Mg-1.5 Cu													
404877A9	Air[10]	15.6	30	78	RET	1.0	90	1	800	Octa	30.1	.2	6928
405073A	Nitrogen	15.8	60	93	RET	1.7	156	10	800	Octa	38.9	.2	6933
MA83 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu													
405536A	Air	14.0	60	85	VAC	(8)	156	10	800	Octa	33.2	.2	6927
405536C	Air	14.0	60	85	CANIT	(8)	156	10	800	Octa	32.0	.2	6924
405536D	Air	14.0	60	84	RET	1.3	94	10	800	Octa	30.1	.2	6925
405536E	Air	14.0	60	88	RET	1.8	156	1	800	Octa	31.0	.2	6926
405536G	Air	14.0	60	85	RET	1.4	156	10	800	Octa	28.2	.1	6922
405481H	Air	13.6	60	(7)	RET	2.1	156	10	800	Octa	37.6	.3	6930
405481J	Air	13.6	60	(7)	RET	1.9	0	0	800	Octa	28.6	.2	6923
405481K	Air	13.6	60	(7)	AVAC	2.5	0	0	800	Octa	22.6	.1	6931
405481L[9]	Air	13.6	None	~50	AVAC	(8)	156	10	700	Octa	32.6	.2	6940
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-0.04 ea. Fe, Si													
404882A	Air	49.3	60	(7)	AVAC	(11)	156	10	800	Octa	39.5	.2	6934
404882B	Air	49.3	60	89	RET	1.6	156	10	800	Octa	32.6	.2	6929
404882C	Air	49.3	60	88	RET	1.2	94	10	800	Octa	30.4	.2	6932

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Compacts prepared by Wet Bag Isotatic Compacting.
3. Percent of theoretical density.
4. See Figure 24 for details of preheat method.
5. All compacts hot pressed in extrusion cylinders at ram face pressures shown.
6. Extruded from 6-3/8" diameter cylinder, extrusion ratio: 12.4:1. (See Figure 1.)
7. Not measured.
8. Approximately 1 to 3 hours. VAC and AVAC: 4 hrs. in furnace.
9. Loose powder, tapped to pack in can.
10. 4" long billet from 170 lb. hot pressed compact.

Table 43

TENSILE AND NOTCHED TENSILE PROPERTIES OF EXTRUSIONS FROM VACUUM OR NITROGEN PREHEATED AND HOT PRESSED COMPACTS

		Fabricating Procedure[5]						Longitudinal Properties					Transverse Properties				
Sample No.	Powder Size[1] µM	Preheat Method[2]	Hot Compact Press ksi	Press Dwell min.	Extrusion Speed Ft/min.	Extrusion Density[3] lbs/cu.in.	Second-Step Age[4] @ 325 F	T.S. ksi	Y.S. ksi	% El. in. 4D	R.A. %	NTS/YS	T.S. ksi	Y.S. ksi	% El. in. 4D	R.A. %	NTS/YS
MA83 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu																	
405536A	14.0	VAC	156	10	.2	.1028	None	(6)					85.0	76.3	9.4	10	1.02
405536A	14.0	VAC	156	10	.2	.1028	6 hrs.	86.8	83.7	13.3	35	1.40	78.6	73.0	10.2	24	1.27
405536C	14.0	CANIT	156	10	.2	.1027	6 hrs.	88.0	84.1	10.2	24	1.32	78.6	72.0	7.0	12	0.79
405536D	14.0	RET	90	10	.2	.1027	6 hrs.	87.8	84.0	11.7	28	1.30	76.2	72.2	3.0	4	0.55
405536E	14.0	RET	156	1	.2	.1027	6 hrs.	88.6	85.1	10.2	24	1.30	77.2	72.0	3.9	7	0.69
405536G	14.0	RET	156	10	1	.1030	6 hrs.	86.3	82.4	11.7	25	1.13	76.2	74.3	7.8	6	.87
405481H	13.6	RET	156	10	3	.1026	6 hrs.	88.9	85.5	10.9	22	1.32	71.9	71.9	1.6	5	0.53
405481J	13.6	RET	None[9]	None	.2	.1026	6 hrs.	88.5	84.5	12.5	26	1.23	79.0	72.9	6.2	8	0.46
405481K	13.6	AVAC	None[9]	None	1	.1027	6 hrs.	85.9	82.8	14.1	41	1.31	79.4	74.6	10.9	22	0.76
405481L	13.6	AVAC[10]	156	10	.2	.1027	6 hrs.	89.7	87.1	14.0	34	1.37	80.2	75.4	6.2	5	1.24
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-0.04 ea. Fe, Si[7]																	
404882A	49.3	AVAC	156	10	.2	.1024	6 hrs.	91.0	89.0	10.2	32	1.13	86.8	83.1	1.6	2	0.48
404882B	49.3	RET	[illegible]	10	.2	.1026	6 hrs.	92.0	89.8	10.2	28	1.16	87.2	83.4	2.3	4	0.49
404882C	49.3	RET	90	10	.2	.1022	6 hrs.	92.4	90.2	11.7	27	1.03	83.1	80.8	1.6	3	0.43
MA65 Alloy: Al-6.5 Zn-2.5 Mg-1.5 Cu																	
405073A	15.8	RET	156	10	.2	(6)	None	84.6	78.6	12.5	14	1.40	82.1	73.6	3.8	4	0.62
404877A9	15.6	RET[7,8]	90	1	.2	(6)	None	94.8	86.7	10.9	12	1.29	79.6	69.0	8.6	10	0.83

Notes:
1. Average Particle Diameter.
2. See text, Figure 24 for method details.
3. Measured in temper with 24 hrs. @ 250 F aging.
4. Extrusions solution heat treated 2 hours @ 920 F, cold water quenched, no room temperature age, artificially aged 24 hours @ 250 F.
5. See Tables 18 and 42 for complete fabricating procedure.
6. Not determined.
7. See Table 41 for detailed alloy and powder description.
8. 4" long billet from 170 lb. hot pressed compact.
9. Compact extruded without hot pressing; extrusion breakout pressures = 28.6 (J) or 22.6 (K).
10. 25 lbs. of loose powder in can preheated to 125 µM pressure. Extruded from 700 V extrusion cylinder.

Table 44

COMPARISON OF PROPERTIES OF EXTRUSIONS FROM VACUUM OR NITROGEN PREHEATED COMPACTS AND EXPERIMENTALLY PRODUCED I/M 7050 AND 7075 EXTRUSIONS

Alloy	Sample No.[8]	Preheat Method	Second-Step Age[2] @ 325	Longitudinal Properties T.S. ksi	Y.S. ksi	% El. in. 4D	NTS/YS	K_Q[3]	Transverse Properties T.S. ksi	Y.S. ksi	% El. in. 4D	NTS/YS	K_{Ic}[4]
MA83[5]	413104	VAC	6 hrs.	89.1	85.8	12.5	1.40[10]	37.8	81.1	75.4	9.4	1.27[10]	34.0
MA83[5]	413103	AVAC	6 hrs.	88.0	85.0	14.1	1.37[10]	35.8	81.4	76.4	7.0	1.24[10]	22.4
MA83[5]	405536C	CANIT	6 hrs.	88.0	84.1	10.2	1.32[10]	(7)	78.6	72.0	7.0	0.79[10]	(7)
7050[6]	413102		20 hrs.	93.4	89.4	14.8	(7)	37.5	83.0	76.2	7.0	(7)	28.0
7075[6]	405295		None	94.9	89.0	(9)	1.31	35.0	80.2	67.8	8.6	1.05	21.8

Notes:
1. See text, Figure 24 for full description.
2. Solution heat treated 2 hours @ 920 F (MA83), 895 F (7050) or 4 hrs. @ 870 F (7075), CWQ, N.A. 4 days (405536C-No N.A.), + 24 hours @ 250 F.
3. ksi $\sqrt{in.}$ - Not valid K_{Ic} per ASTM E399 - specimens not thick enough to achieve plane-strain and linear elastic conditions.
4. ksi $\sqrt{in.}$
5. 1.56" extruded octagonal rod (Figure 1). Extrusion ratio = 12.4
6. 1.56" extruded octagonal rod (Figure 1). Extrusion ratio = 17.1
7. Not determined.
8. 413103 fabricated as 405481L; 413104 fabricated as 405536A (See Table 42).
9. Not determined - Specimens failed to shoulder.
10. Data from Table 43.

Table 45

FUSION EXTRACTED GAS FROM VACUUM PREHEAT P/M EXTRUSIONS

Sample No.	Material	Preheat Method[1]	Hot Compact Pressure ksi	Total Gas[4] ml/100gms	Extracted Gas Analysis-Wt. %							
					H_2	N_2	Ar	Co	Co_2	Methane	O	Water
MA83 Alloy:	Al-8.0 Zn-2.5 Mg-1.0 Cu											
405536 A	P/M	VAC	156	2.4	98.0	1.4	--	--	0.2	0.03	0.2	0.2
405536 C	P/M	CANIT	156	3.5	99.1	0.4	0.02	--	0.1	0.1	--	0.3
405536 G	P/M	RET	156	3.9	99.5	0.3	--	--	--	0.1	--	0.2
405481 K	P/M	AVAC	None[2]	1.5	98.4	--	0.1	0.8	0.2	0.24	--	--
405481 L[3]	P/M	AVAC	156	2.6	98.7	--	0.03	0.9	--	0.1	--	0.1
7075 Alloy:	Al-5.8 Zn-2.4 Mg-1.7 Cu-0.2 Cr											
405295-5B	Ingot	--	None	0.15[5]	89.2	1.1	--	6.5	1.7	1.1	1.5	0.3
7050 Alloy:	Al-6.1 Zn-2.4 Mg-2.3 Cu-0.11 Zr											
379738	Ingot	--	None	0.13	82.8	11.6	--	--	2.7	1.05	1.5	0.3

Notes:
1. See Table 42, Figure 24 for preheat details.
2. Extruded without hot pressing; broke out at 22.6 ksi.
3. Loose powder preheated with vacuum.
4. Gas extracted with sample at 700 C.
5. Ethane = 0.5%
6. 72-011919.

WSC:ds
9/29/72

Table 46

EFFECT OF POWDER SIZE AND COMPOSITION ON
QUENCH SENSITIVITY OF Al-9.0 Zn-2.5 Mg ALLOY EXTRUSIONS

			Percent of Maximum Yield Strength[2]			
			Longitudinal		Transverse	
		Second-Step	Powder Size		Powder Size	
Cu	+Co	Age[1]	16μM	46μM	16μM	46μM
None	None	None	61.4	81.1	61.0	84.2
1.1%	None	None	67.7		64.3	
None	0.81	None	60.7	79.4	60.2	81.1
1.0	0.80	None	53.0		56.9	
None	None	6 hrs.	66.5	84.8	68.1	85.0
1.1	None	6 hrs.	72.3		68.3	
None	0.81	6 hrs.	64.7	78.6	66.8	80.0
1.0	0.80	6 hrs.	57.2		58.0	

Notes: 1. Cu-free alloys were first-step aged 48 hours @ 250 F, second-step aged @ 300 F. Cu-bearing alloys were aged 24 hours @ 250 F, second-step aged @ 325 F.
2. Yield Strength with 3°F/sec. quench rate from 750 to 550 F, as a percentage of yield strength with 160°F/sec. quench rate.

Table 47

BILLET FABRICATING CONDITIONS FOR HOT PRESSED COMPACTS EXTRUDED TO 4" DIAMETER DIE FORGING STOCK

Sample No.	Powder Size µM	Approx. Cold Compact Density[2] %	Preheat Conditions Method[3]	Time hrs.	Temp. °F	Gas	Flow CFH/hr	Hot Compact Pressure ksi	Scalped Billet[4] Dia. in.	Length[5] in.
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu										
404877-D1	15.6	78	Furnace	1.0	1000	Argon	0.29	90	8.7	26.
404877-D2	15.6	78	Furnace	2.0	1000	Argon	0.29	90	8.7	26.
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu										
404880-D3	16.5	78	Furnace	2.3	1000	Argon	0.29	90	8.7	26.
404880-D4	16.5	78	Furnace	2.6	1000	Argon	0.29	90	8.7	26.
MA83 Alloy: High Purity Al-8.0 Zn-2.5 Mg-1.0 Cu										
405481-D7	14.7	77	Furnace	1.2	1000	Argon	0.29	90	8.7	26.
405481-D8	14.7	77	Furnace	1.6	1000	Argon	0.29	90	8.7	26.
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co										
404883-D5	14.7	76	Furnace	2.9	1000	Argon	0.29	90	8.7	26.
404883-D6	14.7	76	Furnace	3.3	1000	Argon	0.29	90	8.7	26.

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Percent of theoretical density - from Table 9.
3. Preheated in a muffle atmosphere furnace immediately before hot pressing.
4. Hot pressed compact: 8.3" to 9.2" iameter (tapered) x 28" long.
5. Equal amounts scalped from each end of hot pressed billet.

WSC:km
8-8-72

Table 48

COMPACTS FABRICATED TO 4" DIAMETER STOCK FOR DIE FORGING[2]

Alloy	S. No.	Extrusion No.	Reheat Temp. °F	Breakout Pressure ksi	Preheat Time hrs.	Preheat Temp. °F
MA65: 6.5 Zn-2.3 Mg-1.5 Cu	404877-D1	6078	720	33.7	1.0	1000
	404877-D2	6079	710	33.2	2.0	1000
MA66: 8.0 Zn-2.5 Mg-1.0 Cu	404880-D3	6080	710	30.3	2.3	1000
	404880-D4	6081	710	29.6	2.6	1000
MA83: 8.0 Zn-2.5 Mg-1.0 Cu	405481-D7	6607	700	35.8	1.2	1000
	405481-D8	6608	700	32.2	1.6	1000
MA67: 8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co	404883-D5	6082	720	29.4	2.9	1000
	404883-D6	6083	720	30.3	3.3	1000
IM[1] 7075	4052951	6084	700	35.6	24.0	860

Notes: 1. Ingot Metallurgy.

2. Powders of 15 µM APD, cold pressed to 75% density, preheated 1-3 hours @ 1000 F and hot pressed at 90 ksi. Compact scalped 1/8" off diameter, induction reheated to 700 F and extruded with 5.4:1 Extrusion Ratio from 9-1/4" diameter cylinder at less than 3 feet/minute extrusion speed.

WSC:ds
9/29/72

Table 49

TENSILE PROPERTIES OF P/M AND 7075 ALLOY 9078 DIE FORGINGS

Sample No.	Powder Size[1] µM	Preheat Atmosphere[2]	Quench Water Temp. °F	Stress Relief	Second Step Age[3] @ 325 F	Web Electrical Conductivity % IACS	Specimen Location[4]	Longitudinal Properties T.S. ksi	Longitudinal Y.S. ksi	Longitudinal El. % in. 4D	Longitudinal R.A. %	Longitudinal NTS/YS	Direction[5]	Transverse Properties T.S. ksi	Transverse Y.S. ksi	Transverse El. % in. 4D	Transverse R.A. %	Transverse NTS/YS
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu																		
404877-D1F	15.6	Argon	80	None	None		Flange	85.6	74.4	13.2	18	1.25	N	76.9	69.0	3.0	4	0.68
						35.2	Web	89.1	79.4	13.8	20	1.07	T	85.9	75.4	13.1	16	1.10
404877-D2F	15.6	Argon	150	None	None		Flange	79.7	66.4	14.3	21	1.14	N	71.2	59.1	7.5	12	0.76
						39.0	Web	78.1	65.4	14.5	23	1.20	T	77.9	65.3	13.0	15	1.14
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu																		
404880-D3F	16.5	Argon	80	None	None		Flange	90.5	81.9	10.7	--	1.05	N	84.0	75.9	3.4	6	0.55
						34.3	Web	91.2	84.2	12.7	19	0.83	T	87.9	81.2	8.0	10	0.76
404880-D3R	16.5	Argon	80	None	6 hrs.		Flange	86.6	81.8	12.5	24	1.11	N	77.5	74.4	1.4	3	0.50
						41.0	Web	88.4	84.4	11.7	24	0.90	T	88.0	84.1	11.2	23	0.83
404880-D4F	16.5	Argon	150	None	None		Flange	87.2	76.4	10.7	15	1.07	N	76.8	65.2	2.5	3	0.57
						38.7	Web	84.6	74.8	12.6	16	1.00	T	82.8	73.1	11.8	15	0.81
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co																		
404883-D5F	14.7	Argon	80	None	None		Flange	96.7	88.3	10.0	9	0.73	N	87.8	79.3	2.9	2	0.49
						33.7	Web	100.5	92.8	8.9	12	0.63	T	97.4	89.2	9.6	14	0.66
404883-D5R	14.7	Argon	80	None	6 hrs.		Flange	89.3	83.1	9.3	14	0.88	N	84.4	77.6	5.0	6	0.56
						39.3	Web	90.7	85.8	9.5	19	0.75	T	90.3	85.6	10.0	16	0.75
404883-D6F	14.7	Argon	150	None	None		Flange	89.0	77.2	9.6	10	0.78	N	81.0	71.6	2.2	4	0.47
						36.9	Web	84.7	74.5	10.4	18	0.78	T	83.8	73.0	9.0	12	0.79
7075 Alloy: Al-5.8 Zn-2.4 Mg-1.7 Cu-0.2 Cr																		
4052952R	I/M[6]	-----	80	None	None		Flange	92.9	82.9	11.8	15	1.34	N	80.1	70.6	9.3	24	0.94
							Web	95.2	86.0	12.0	18	1.30	T	92.0	81.8	11.0	13	1.22
405295-2F	I/M[6]	-----	150	None	None		Flange	82.8	69.1	10.7	12	1.36	N	71.0	58.6	8.6	14	1.16
							Web	79.4	69.0	13.0	16	1.36	T	81.0	68.2	10.5	14	1.34

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Isostatically pressed 170 lb. green compacts preheated in flowing argon to 1000 F, hot pressed at 90 ksi, scalped, reheated and extruded from a 9-1/4" diameter cylinder to 4" diameter rod (Extrusion Ratio (E.R.) = 5.4:1) for stock for production plant die forging.
3. Die forgings solution heat treated 2 hours @ 920 F (P/M) or 880 F (I/M 7075), quenched as shown, aged 4-7 days at room temperature + 24 hours @ 250 F + further aging @ 325 F as shown.
4. See Figure 47 for flange and web locations tested.
5. N = Short transverse specimens with specimen adjacent to and normal to the die parting plane.
   T = Long transverse specimens normal to the major stock dimension.
6. I/M = Ingot Metallurgy 7075. Extrusion billet (8-3/4" dia.) machined from 11" diameter D.C. ingot produced in a production plant. Forging stock (4" diameter) extruded in conjunction with P/M forging stock (E.R. = 5.4:1), die forged in a production plant in conjunction with the P/M die forging.

Table 50

ALTERNATE IMMERSION STRESS-CORROSION PERFORMANCE OF P/M 9078 DIE FORGINGS.
A.I. TEST WITH SHORT-TRANSVERSE TENSILE BARS (ACROSS THE PARTING PLANE) - FEDERAL TEST METHOD 823

Sample No.[1]	Quench Water Temp.-°F	Second-Step Age[2] @ 325 F	Flange Properties LYS ksi	Flange Properties STYS ksi	Days to Failure at Indicated Stress Level in A.I. Test 25 ksi	30 ksi	35 ksi	40 ksi	45 ksi
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu									
404877-D1F	80	None	74.4	69.0	45,46,63	19,34,47	4,4,34	4,4,5	3,5,P
404877-D2F	150	None	66.4	59.1	P[3],P,P	49,P,P	7,30,52	3,5,27	3,3,4
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu									
404880-D3F	80	None	78.5	75.9	27,30,34	21,29,34	6,17,35	14,19,20	9,16,16
404880-D3R	80	6 hrs.	81.8	74.4	54,P,P	36,42,65	29,29,32	25,32,40	24,30,32
404880-D4F	150	None	76.4	65.2	68,68,P	63,P,P	29,34,43	18,29,50	8,34,34
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co									
404883-D5F	80	None	88.3	79.3	30,P,P	41,45,P	18,20,21	11,15,29	16,17,21
404883-D5R	80	6 hrs.	83.1	77.6	62,P,P	69,P,P	69,83,P	69,75,P	51,61,63
404883-D6F	150	None	77.2	71.6	P,P,P	P,P,P	P,P,P	58,58,60	17,24,68
I/M 7075 Alloy									
405295-2F	80	None	82.9	70.6	2,2,3	2,3,3	2,3,3	2,2,2	1,2,2
405295-2R	150	None	69.1	58.6	3,4,4	3,3,3	2,3,3	2,2,3	2,2,2

Notes: 1. All P/M forgings from 15µM APD powders.
2. First-step aged 24 hours @ 250 F.
3. P = pass 84 days exposure in A.I. test.

WSC/lmk
8/11/72

Table 51

BILLET FABRICATING CONDITIONS FOR HOT PRESSED COMPACTS HAND FORGED TO 2" x 10" x 47"

Sample No.	Powder Size[1] μM	Approx. Cold Compact Density[2] %	Preheat Conditions: Method[3]	Time hrs.	Temp °F	Gas	Flow CFH/lb	Hot Compact Pressure ksi	Scalped Billet: Dia. in.	Length[5] in.
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu										
404877-M1	15.6	78	Furnace	1.7	1000	Argon	0.29	90	7.5	22.5
404877-M2	15.6	78	Furnace	2.0	1000	Argon	0.29	90	7.5	22.5
404877-M3	15.6	78	Furnace	2.3	1000	Argon	0.29	90	7.5	22.5
404879-N2	48.5	80	Furnace	1.9	1000	Argon	0.29	90	7.5	22.5
404879-M4	48.5	80	Furnace	1.0	1000	Argon	0.29	90	7.5	22.5
404879-M5	48.5	80	Furnace	1.2	1000	Argon	0.29	90	7.5	22.5
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu										
404880-M7	16.5	78	Furnace	2.7	1000	Argon	0.29	90	7.5	22.5
404880-M8	16.5	78	Furnace	3.0	1000	Argon	0.29	90	7.5	22.5
404880-M9	16.5	78	Furnace	1.0	1000	Argon	0.29	90	7.5	22.5
404882-M10	49.3	76	Furnace	1.2	1000	Argon	0.29	90	7.5	22.5
404882-M11	49.3	76	Furnace	1.5	1000	Argon	0.29	90	7.5	22.5
MA67 Alloy: Al 8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co										
404883-M12	14.7	76	Furnace	2.0	1000	Argon	0.29	90	7.5	22.5
404883-M13	14.7	76	Furnace	2.4	1000	Argon	0.29	90	7.5	22.5
404883-M14	14.7	76	Furnace	0.8	1000	Argon	0.29	90	7.5	22.5

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Percent of theoretical density - From Table 9.
3. Preheated in a muffle atmosphere furnace immediately before hot pressing.
4. Hot pressed compact: 8.3" to 9.2" diameter (tapered) x 28" long.
5. Equal amounts scalped from each end of hot pressed billet.

WSC:km
8-8-72

Table 52

TENSILE PROPERTIES OF P/M 2"x10"x47" HAND FORGINGS

Sample No.	Powder Size[1] μM	Preheat Atmosphere[2]	Temper: Quench Water Temp. °F	Temper: Stress Relief[3]	Temper: Second-Step Age[4] @ 325 F	Electrical Conductivity % IACS	Longitudinal Properties: T.S. ksi	Y.S. ksi	El. % in 4D	R of A %	NTS/YS	Long-Transverse Properties: T.S. ksi	Y.S. ksi	El. % in 4D	R of A %	NTS/YS	Short-Transverse Properties: T.S. ksi	Y.S. ksi	El. % in 4D	R of A %	NTS/YS
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu																					
404877M2B	15.6	Argon	80	2%	None	34.6	82.7	74.2	12.5	18	1.04	82.4	70.0	14.1	28	1.10	75.6	62.2	2.4	2	0.63
404877M2C	15.6	Argon	80	2%	4 hrs.	41.3	75.4	68.0	8.8	19	1.15	77.2	67.7	11.7	27	1.06	68.9	62.5	1.6	0	0.58
404877M1C	15.6	Argon	150	None	None	35.7	79.7	69.6	12.5	21	1.25	79.4	68.2	13.0	20	1.12	74.4	65.0	4.7	3	0.78
404877M3C	15.6	Argon	180	None	None	37.1	76.9	66.7	13.0	16	1.22	75.6	64.4	13.5	17	1.12	71.4	63.2	4.7	5	0.75
404879N2B	48.5	Argon	80	2.8%	None	32.7	85.1	76.7	14.0	20	1.04	81.7	69.6	10.8	12	1.10	74.1	68.4	2.4	1	0.48
404879N2C	48.5	Argon	80	2.8%	4 hrs.	37.1	77.8	71.8	10.3	20	1.13	82.8	73.8	10.2	18	1.00	72.8	70.0	1.6	3	0.60
404879M4C	48.5	Argon	150	None	None	33.3	76.6	69.3	9.5	13	1.19	80.2	68.0	9.8	11	1.12	64.2	--	--	-	37.6[6]
404879M5C	48.5	Argon	180	None	None	33.7	70.9	64.4	11.8	36	1.21	80.0	68.1	10.5	12	1.04	60.0	--	--	-	31.5[6]
MA65 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu																					
404880M8A	16.5	Argon	80	2.2%	None	33.7	87.2	80.0	12.0	14	0.91	88.6	78.4	10.9	26	0.83	79.2	68.2	1.6	0	0.42
404880M8B	16.5	Argon	80	2.2%	2 hrs.	38.0	82.4	76.8	10.0	24	0.93	81.8	73.5	11.7	28	0.88	78.9	67.9	3.1	2	0.58
404880M7B	16.5	Argon	150	None	None	38.1	83.6	76.2	11.5	14	0.89	82.4	73.6	9.2	18	0.86	75.7	70.6	3.1	1	0.42
404880M9C	16.5	Argon	180	None	None	38.0	78.1	69.8	11.0	16	1.23	78.2	68.6	11.8	16	1.16	73.5	68.4	1.6	3	0.73
404882M10A	49.3	Argon	80	2.2%	None	31.8	95.9	91.0	10.0	16	0.73	97.2	88.6	8.6	18	0.71	49.0	--	--	-	25.6[6]
404882M10B	49.3	Argon	80	2.2%	4 hrs.		82.4	76.9	6.8	18	0.96	86.0	78.3	9.4	17	0.87	61.4	--	1.6	1	31.9[6]
404882M11B	49.3	Argon	180	None	None	33.3	81.5	75.4	8.0	15	0.92	90.7	83.0	7.2	8	0.70	35.7	--	--	-	21.7[6]
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co																					
404883M13A	14.7	Argon	80	2.5%	None	33.0	89.2	81.8	6.5	8	0.69	91.2	80.4	10.9	21	0.71	82.9	72.0	1.6	1	0.36
404883M13B	14.7	Argon	80	2.5%	2 hrs.		83.2	76.4	8.8	17	0.86	85.0	74.0	10.2	25	0.85	78.0	69.2	1.6	1	0.62
404883M12B	14.7	Argon	150	None	None	33.7	83.6	74.8	6.3	5	0.78	83.3	73.1	7.0	11	0.76	78.3	70.6	3.1	1	0.42
404883M14C	14.7	Argon	180	None	None	36.1	80.0	70.6	8.8	12	0.94	80.8	70.0	8.8	10	0.85	71.9	66.4	1.6	0	0.45
7075 Alloy: Al-5.8 Zn-2.4 Mg-1.7 Cu-0.2 Cr																					
405295	I/M[5]	--	80	2.4%	None	31.5	81.4	69.9	10.5	16	1.42	79.6	68.2	14.0	22	1.42	74.7	59.8	5.4	6	0.96

Notes:
1. 2"x10"x47" H.F. Average Particle Diameter.
2. Isostatically pressed 170 lb green compacts preheated to 1000 F in flowing argon in an atmosphere furnace, hot pressed at 90 ksi, scalped, reheated and hand forged to 2.2"x10"x47".
3. Compressive Stress Relief: Percent decrease in thickness for compressing within 8 hours after quench.
4. Forgings solution heat treated 2 hours @ 920 F (880 F-7075) quenched as shown, aged 4-7 days at room temperature + 24 hours @ 250 F + second-step age indicated hours @ 325 F.
5. Forged from 7.5" dia. x 22.5" long billet taken from a 11" diameter D.C. Ingot.
6. Notched Tensile Strength.

WSC:slo
8/21/72

Table 53

ALTERNATE IMMERSION STRESS-CORROSION PERFORMANCE OF P/M 2" THICK HAND FORGINGS.
SHORT-TRANSVERSE TENSILE BARS TESTED IN A.I. BY FEDERAL TEST METHOD 823

Sample No.	Powder Size[1] µM	Quench Water Temp.-°F	Second-Step Age[2] @ 325 F	LYS ksi	STYS ksi	Days to Failure at Indicated Stress Level in A.I. Test: 25 ksi	30 ksi	35 ksi	40 ksi	45 ksi
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu										
404877-M2B	15.6	80	None	74.2	62.2	4,25,26	2,2,29	2,2,2	1,1,2	1,2,2
404877-M2C	15.6	80	4 hrs.	68.0	62.5	P[3],P,P	62,73,84	53,65,78	52,52,52	29,42,43
404877-M1C	15.6	150	None	69.6	65.0	2,4,59	2,2,2	1,1,1	1,1,1	1,1,1
404877-M3C	15.6	180	None	66.7	63.2	3,24,80	4,4,5	3,11,11	2,2,3	2,2,2
404879-N2C	48.5	80	4 hrs.	71.8	70.0	5,21,25	3,3,3	3,3,3	2,2,2	2,2,2
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu										
404880-M8A	16.5	80	None	80.0	68.2	20,27,43	14,24,28	14,14,19	7,17,17	7,9,11
404880-M8B	16.5	80	2 hrs.	76.8	67.9	52,52,53	31,34,35	29,29,34	18,24,24	15,17,22
404880-M7B	16.5	150	None	76.2	70.6	28,32,44	15,15,24	8,16,17	4,5,5	3,4,4
404880-M9C	16.5	180	None	69.8	68.4	42,52,60	33,33,43	8,24,25	3,4,16	1,2,3
404882-M10B	49.3	80	4 hrs.	76.9	--	6,32,32	3,3,14	3,3,8	3,4,4	3,3,3
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co										
404883-M13A	14.7	80	None	81.8	72.0	P,P,P	4,20,P	4,16,34	4,4,48	4,4,4
404883-M13B	14.7	80	2 hrs.	76.4	69.2	P,P,P	78,P,P	57,57,82	31,39,52	29,39,39
404883-M12B	14.7	150	None	74.8	70.6	41,P,P	4,44,56	12,16,30	3,4,4	4,4,4
404883-M14C	14.7	180	None	70.6	66.4	P,P,P	76,P,P	4,4,11	24,68,73	16,28,32
I/M 7075 Alloy										
405295-Q2		80	None	69.9	59.8	2,2,2	2,2,2	2,3,3	2,3,3	2,3,3

Notes: 1. Average Particle Diameter.
2. First-step aged 24 hours @ 250 F.
3. P = pass 84 days exposure without failure.

WSC/lmk
8/11/72

TABLE 54

EFFECT OF SECOND-STEP AGE ON LONGITUDINAL
TENSILE PROPERTIES OF 2" THICK x 10" WIDE HAND FORGINGS[1]

Sample		Alloy	Powder Size[2] µM	Second-Step Age[3] hrs @ 325°F	LONGITUDINAL PROPERTIES[4] T.S. ksi	Y.S. ksi	El. % in 4D	R. of A. %
404877	M2	MA65	15.6	0	81.2	71.8	14.0	21
				4	75.6	67.8	11.0	28
				16	72.7	64.8	12.0	36
404879	N2	MA65	48.5	0	83.0	75.2	14.0	22
				4	78.1	71.5	12.0	30
				16	79.8	72.1	13.5	34
404880	M8	MA66	16.5	0	86.8	79.8	12.0	20
				4	77.8	71.5	12.0	30
				16	72.7	64.2	15.0	42
404882	M10	MA66	49.3	0	95.2	89.6	11.0	18
				4	85.2	79.6	12.0	28
				16	81.8	74.6	14.0	38
404883	M13	MA67	14.7	0	91.3	82.9	10.0	17
				4	78.2	68.8	10.0	20
				16	73.8	63.4	12.0	28

Notes:
1. All forgings heat treated, cold-water quenched, compressive stress relieved and aged 24 hrs @ 250 F (as shown in Table 52) before second-step aging.
2. Average Particle Diameter.
3. Zero hours @ 325 F is single-step aged only.
4. M.T. No. 051071-L, dated 8-31-71.

WSC:km
8-4-72

Table 55

P/M BILLET FABRICATING CONDITIONS FOR HOT PRESSED COMPACT
HAND FORGED TO 5" SQ. 3" SQ., OR 2" SQ.

Sample	Powder Size[1] µM	Approx. Cold Compact Density[2] - %	Preheat Conditions: Method[3]	Time hrs	Temp. °F	Gas	Flow CFH/lb	Hot Compact Pressure ksi	Compact Density lbs/in.[3]	Scalped Billet[4]: Dia. in.	Lengths[5] in.
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu											
404877-A1	85	78	Retort	1.0	1000	Argon	0.17	90		7.5	19
404877-A2	85	77	Retort	1.3	1000	Argon	0.35	90		7.5	19
404877-A3	85		Retort	1.6	1000	Argon	0.75	90		7.5	19
404877-A4	85	78	Retort	5.0	1000	Argon	0.35	90		7.5	19
404877-A5	85		Retort	1.7	1000	Argon	0.35	90		7.5	19
404877-A6	85		Retort	1.0	950	Argon	0.35	90		7.5	19
404877-A7	85		Retort	1.0	1050	Argon	0.35	90		7.5	19
404877-A8	85		Retort	1.3	1000	Nitrogen	0.35	90		7.5	19
404877-A9	85		Retort	1.0	1000	Nitrogen	0.35	90		7.5	19
404877-A10	85		Retort	1.3	950	Nitrogen	0.75	90		7.5	19
404877-A12	85		Retort	2.0	1000	Air	0	90		7.5	19
404877-A13	85		Furnace	1.1	1000	Air	0	90		7.5	19
404877-B1	85		Furnace	1.0	1000	Argon	0.29	90		7.5	19
404877-C1	85	77	Furnace	1.0	1000	Argon	0.29	90		7.75	19
404877-C2	85	78	Furnace	1.3	1000	Argon	0.29	90		7.75	19
404877-C3	85	77	Furnace	1.7	1000	Argon	0.29	90		7.75	19
404877-C4	85	78	Furnace	2.0	1000	Argon	0.29	90		7.75	19
404877-C5	85		Furnace	1.0	1000	Argon	0.29	90		8.25	19
404877-C6	85		Furnace	2.4	1000	Argon	0.29	90		8.0	19
404877-C7	85		Furnace	1.3	1000	Argon	0.29	90		7.75	19
404877-C8	85		Furnace	1.7	1000	Argon	0.29	90		7.75	19
404877-C9	85		Furnace	1.2	1000	Argon	0.29	90		Unscalped	
404877-H1	85		Furnace	2.0	1000	Argon	0.29	90		7.5	19
404877-P6	85		Furnace	5.0	1000	Argon	0.29	90		7.5	22.5
404877-P7	85		Furnace	24.0	1000	Argon	0.29	90		7.5	22.5
404878-B2	50		Furnace	1.3	1000	Argon	0.29	60		7.5	19
404878-B3	50		Furnace	1.5	1000	Argon	0.29	75		7.5	19
404878-B4	50		Furnace	1.8	1000	Argon	0.29	90	.1021	7.5	19
404879-B5	10		Furnace	2.0	1000	Argon	0.29	90		7.5	19

Table 55 (Cont'd.)

P/M BILLET FABRICATING CONDITIONS FOR HOT PRESSED COMPACT
HAND FORGED TO 5" SQ., 3" SQ., OR 2" SQ.

Sample	Powder Size[1] µM	Approx. Cold Compact Density[2] - %	Preheat Conditions Method[3]	Time hrs	Temp. °F	Gas	Flow CFH/lb	Hot Compact Pressure ksi	Compact Density lbs/in.³	Scalped Billet[4] Dia. in.	Lengths[5] in.
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu											
404880-B6	85	77	Furnace	1.0	1000	Argon	0.29	90		7.5	19
404881-B7	50	77	Furnace	1.2	1000	Argon	0.29	60		7.5	19
404881-B8	50		Furnace	1.5	1000	Argon	0.29	75		7.5	19
404881-B9	50	77	Furnace	1.7	1000	Argon	0.29	90	.1029	7.5	19
404882-B10	10		Furnace	1.0	1000	Argon	0.29	90		7.5	19
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co											
404883-B11	85		Furnace	1.0	1000	Argon	0.29	90	.1043	7.5	19
404883-B12	85	76	Furnace	1.3	1000	Argon	0.29	90	.1043	7.5	19
404884-B13	50	76	Furnace	1.7	1000	Argon	0.29	60		7.5	19
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co											
404884-B14	50	76	Furnace	2.0	1000	Argon	0.29	75		7.5	19
404885-B15	50	76	Furnace	2.1	1000	Argon	0.29	90		7.5	19
404885-B16	10	75	Furnace	1.0	1000	Argon	0.29	60	.1038	Cracked in loading for hot press	
404885-B17	10	79	Furnace	1.3	1000	Argon	0.29	90	.1038	Cracked in loading for hot press	

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Percent of theoretical density from Table 9.
3. Preheated in a muffle atmosphere furnace immediately before hot pressing.
4. Hot pressed compact: 8.3 to 9.2" diameter (tapered) x 28" long.
5. Equal amounts scalped from each end of hot pressed billet.

Table 56

ULTRASONIC AND VISUALLY RATED QUALITY
OF P/M HAND FORGINGS

Sample Number	Powder Size[1] µM	Forging Section	Ultrasonic Quality: Volume[2] of Sound Forging in.^{3}	Ultrasonic Quality: Billet[3] Volume in.^{3}	Ultrasonic Quality: % Metal Recovery[4]	Visual Quality[5]: End Cracking	Visual Quality[5]: Face Cracking
MA65 Alloy: 6.5 Zn-2.3 Mg-1.5 Cu							
404877-A1	15.6	5" Sq. Stepped to 3" Sq.	654	758	86	A,B	B,B
-A2	15.6	5" Sq. Stepped to 3" Sq.	684	758	90	A,D	B,B
-A3	15.6	5" Sq. Stepped to 3" Sq.	671	758	89	A,A	A,B
-A4	15.6	5" Sq. Stepped to 3" Sq.	702	758	93	A,A	A,A
-A5	15.6	5" Sq. Stepped to 3" Sq.	671	758	89	A,A	A,A
-A6	15.6	5" Sq. Stepped to 3" Sq.	678	758	89	A,A	B-,B
-A7	15.6	5" Sq. Stepped to 3" Sq.	672	758	89	A,B	A,A
-A8	15.6	5" Sq. Stepped to 3" Sq.	664	758	88	A,A	A,A
-A9	15.6	5" Sq. Stepped to 3" Sq.	682	758	90	A,A	A,A
-A10	15.6	5" Sq. Stepped to 3" Sq.	678	758	89	A,A	A,A
-A12	15.6	5" Sq. Stepped to 3" Sq.	689	758	91	A,A	D-,C
-A13	15.6	5" Sq. Stepped to 3" Sq.	135	758	18	E,E	E,E
-B1	15.6	5" Sq. Stepped to 3" Sq.	716	758	94	A,A	B,B-
-C1	15.6	5" Sq.	896	896	100	A	C-
-C2	15.6	5" Sq.	622	896	70	A	C
-C3	15.6	5" Sq.	838	896	94	A	C-
-C4	15.6	5" Sq.	595	896	66	B	D
-C5	15.6	5" Sq.	1000	1000	100	B-	C
-C6	15.6	5" Sq.	925	925	100	A	B
-C7	15.6	5" Sq.	852	896	95	A	C
-C8	15.6	5" Sq.	840	840	100	A	B
-C9	15.6	5" Sq.	832	1700	49	E	E
-H1	15.6	5" Sq., 3-1/2" Sq., 2" Sq. - Stepped	745	745	100	A	A
-J1	15.6	5" x 10"	646	1700	38	A,E[5]	D
-J2	15.6	5" x 10"	693	1700	41	A,E[5]	E

Table 56 (Cont'd.)

ULTRASONIC AND VISUALLY RATED QUALITY
OF P/M HAND FORGINGS

Sample Number	Powder Size[1] μM	Forging Section	Ultrasonic Quality: Volume[2] of Sound Forging in.³	Ultrasonic Quality: Billet[3] Volume in.³	Ultrasonic Quality: % Metal Recovery[4]	Visual Quality[5]: End Cracking	Visual Quality[5]: Face Cracking
-K1	15.6	5" x 10"	921	1700	54	B,E[6]	C
-N1	15.6	5" x 10"	1029	1700	60	A,E[6]	E
-M1	15.6	2.2" x 10"	832	995	84	A	A
-M2	15.6	2.2" x 10"	799	995	80	D	D
-M3	15.6	2.2" x 10"	765	995	77	A	A
-P6	15.6	5" Sq.					
-P7	15.6	5" Sq.					
-P8	15.6	5" x 10"					
MA65 Alloy: 6.5 Zn-2.3 Mg-1.5 Cu							
404878-B2	23.9	5" Sq. Stepped to 3" Sq.	703	758	93	B,C	A-,C
-B3	23.9	5" Sq. Stepped to 3" Sq.	660	758	87	A,C-	A,C-
-B4	23.9	5" Sq. Stepped to 3" Sq.	621	758	82	A,D-	C,C
404879-B5	48.5	5" Sq. Stepped to 3" Sq.	112	758	15	E,E	E,E
-K2	48.5	5" x 10"	409	1700	24	E	E
-M4	48.5	2.2" x 10"	556	995	56	D	C
-M5	48.5	2.2" x 10"	476	995	56	D	D
-N2	48.5	2.2" x 10"	669	995	67	D	B
-X6	48.5	5" x 10"					
MA66 Alloy: 8.0 Zn-2.5 Mg-1.0 Cu							
404880-B6	16.5	5" Sq. Stepped to 3" Sq.	739	758	98	A,A	B,B
-J3	16.5	5" x 10"	420	1700	25	A,E[6]	E
-J4	16.5	5" x 10"	667	1700	39	A,E[6]	D
-K3	16.5	5" x 10"	648	1700	38	D,E[6]	D
-M7	16.5	2.2" x 10"	769	995	77	B	A
-M8	16.5	2.2" x 10"	804	995	81	C	B
-M9	16.5	2.2" x 10"	822	995	83	B	C
-N3	16.5	5" x 10"	859	1700	50	A,E[6]	E

Table 56 (Cont'd.)

ULTRASONIC AND VISUALLY RATED QUALITY
OF P/M HAND FORGINGS

Sample Number	Powder Size[1] μM	Forging Section	Ultrasonic Quality: Volume[2] of Sound Forging $in.^3$	Ultrasonic Quality: Billet[3] Volume $in.^3$	Ultrasonic Quality: % Metal Recovery[4]	Visual Quality[5]: End Cracking	Visual Quality[5]: Face Cracking
404881-B7	21.8	5" Sq. Stepped to 3" Sq.	662	758	88	D,B	C-,B
-B8	21.8	5" Sq. Stepped to 3" Sq.	664	758	88	A,B	A,B
-B9	21.8	5" Sq. Stepped to 3" Sq.	632	758	83	A,B-	D,D
404882-B10	49.3	5" Sq. Stepped to 3" Sq.	320	758	42	C-,E	E,E
-K4	49.3	5" x 10"	0	1700	0	D,E[6]	E
-N4	49.3	5" x 10"	549	1700	32	D,E[6]	E
-M10	49.3	2.2" x 10"	533	995	54	E	C
-M11	49.3	2.2" x 10"	539	995	54	E	D
MA67 Alloy: 8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co							
404883-B11	14.7	5" Sq. Stepped to 3" Sq.	688	758	91	A,B	B,B
-B12	14.7	5" Sq. Stepped to 3" Sq.	671	758	89	A,A	B,B
-J5	14.7	5" x 10"	854	1700	50	D,E[6]	D
-K5	14.7	5" x 10"	483	1700	28	E,E[6]	D
-M12	14.7	2.2" x 10"	826	995	83	D	B
-M13	14.7	2.2" x 10"	788	995	79	C	A
-M14	14.7	2.2" x 10"	878	995	88	B	B
-N5	14.7	5" x 10"	848	1700	50	D,E[6]	E

Table 56 (Cont'd.)

ULTRASONIC AND VISUALLY RATED QUALITY
OF P/M HAND FORGINGS

Sample Number	Powder Size[1] μM	Forging Section	Ultrasonic Quality: Volume[2] of Sound Forging in.^{3}	Ultrasonic Quality: Billet[3] Volume in.^{3}	Ultrasonic Quality: % Metal Recovery[4]	Visual Quality[5]: End Cracking	Visual Quality[5]: Face Cracking
404884-B13	22.7	5" Sq. Stepped to 3" Sq.	671	758	89	A,B	B,B
-B14	22.7	5" Sq. Stepped to 3" Sq.	682	758	90	A,D	A,C-
-B15	22.7	5" Sq. Stepped to 3" Sq.	619	758	82	A,B-	B-B-

Notes:
1. Average Particle Diameter.
2. Volume of forging of Ultrasonic SNT Class A quality.
3. Volume of scalped billet minus volume of any steps.
4. Percent metal Recovery = $\frac{\text{Volume of SNT Class A Forging}}{\text{Billet Volume}}$ X 100.
5. Visual Quality Ratings shown are for a single forging except for the 5" sq. stepped to 3" sq. forging, which show the 5" sq., then the 3" sq. forging quality.
   Visual Quality Ratings:

	Faces	Ends
A	Practically perfect	Practically perfect
B	Slight tears	Surface tears
C	Slight checks	Surface checks
D	Checks, small cracks	Checks, small cracks
E	All severely cracked	Severe crack

6. Quality rating of one end, quality of the other end.

Table 57

EFFECT OF ALLOY, POWDER SIZE AND HOT COMPACTING PRESSURE ON FORGING QUALITY - 3" SQ. AND 5" SQ. HAND FORGINGS

	Hot Compacting Pressure[3]						
	60 ksi			75 ksi	90 ksi		
	Powder Size[6]			Powder Size	Powder Size		
Alloy[5]	15	23	50	23	15	23	50
% Metal Recovery							
MA65		93		87	94	82	15
MA66		88		88	98	83	42
MA67	91	89	(2)	90	89	82	(2)
Face Cracking - 3" Sq. Forgings[4]							
MA65		C		C-	B-	C	E
MA66		B		B	B	D	E
MA67	B	B		C-	B	B-	(2)
Face Cracking - 5" Sq. Forgings[4]							
MA65		A-		A	B	C	E
MA66		C-		A	B	D	E
MA61	B	B	(2)	A	B	B-	(2)
End Cracking - 3" Sq. Forgings[4]							
MA65		C		C-	A	D-	E
MA66		B		B	A	B-	E
MA67	B	B	(2)	D	A	B-	(2)
End Cracking - 5" Sq. Forgings[4]							
MA65		B		A	A	A	E
MA66		D		A	A	A	C-
MA67	A	A	(2)	A	A	A	(2)

Notes:

1. Percent Metal Recovery = $\frac{\text{Volume of SNT Class A Forging}}{\text{Volume of Scalped Billet}} \times 100.$
2. Cracked during loading for hot press.
3. Other processing conditions for forgings B1 to B17 shown in Table 55.
4. Visual Quality Ratings:

	FACES	END
A	Practically perfect	Practically perfect
B	Slight tears	Surface tears
C	Slight checks	Surface checks
D	Checks, small cracks	Checks, small cracks
E	All severely cracked	Severe cracks

5. See Table 5 for alloy composition
6. Average Particle Diameter in uM.

Table 58

ULTRASONIC AND VISUALLY RATED
QUALITY OF 2.2" x 10" HAND FORGINGS

Alloy	Forgings from 15μM Powder		Forgings from 50μM Powder	
Ultrasonic Quality - % Metal Recovery[1]				
MA65	Average of Forgings M1, M2 and M3:	80%	Average of Forgings N2, M4 and M5:	57%
MA66	Average of Forgings M7, M8 and M9:	80%	Average of Forgings M10 and M11:	54%
MA67	Average of Forgings M12, M13 and M14:	83%		
Visual Quality - Face Cracking[2]				
MA65	Average of Forgings M1, M2 and M3:	B	Average of Forgings N2, M4 and M5:	C
MA66	Average of Forgings M7, M8 and M9:	B	Average of Forgings M10 and M11:	C-
MA67	Average of Forgings M12, M13 and M14:	B+		
Visual Quality - End Cracking[2]				
MA65	Average of Forgings M1, M2 and M3:	B	Average of Forgings N2, M4 and M5:	D
MA66	Average of Forgings M7, M8 and M9:	C+	Average of Forgings M10 and M11:	E
MA67	Average of Forgings M12, M13 and M14:	C		

Notes:
1. Percent Metal Recovery = 100 x Volume SNT Class A/995 cu. in.
2. Visual Quality Rating:

	FACES	ENDS
A	Practically perfect	Practically perfect
B	Slight tears	Surface tears
C	Slight checking	Slight checking
D	Checking, small cracks	Checking, small cracks
E	Medium, large cracks	Medium, severe cracks

3. Other processing conditions for forgings M1 to M14 and N2 are shown in Table 51.

WSC:km
8-3-72

Table 59

ULTRASONIC AND VISUALLY RATED
QUALITY OF 5" x 10" PREFORGED ROLLING STOCK

Alloy	Forgings from 15μM Powder		Forgings from 50μM Powder	
Ultrasonic Quality - % Metal Recovery[1]				
MA65	Average - Forgings J1, J2, K1 and N1:	48%	Forging K2:	24%
MA66	Average - Forgings J3, J4, K3 and N3:	38%	Average - Forgings K4 and N4:	16%
MA67	Average - Forgings J5, K5 and N5:	43%		
Visual Quality - Face Cracking[2]				
MA65	Average - Forgings J1, J2, K1 and N1:	D-	Forging K2:	E
MA66	Average - Forgings J3, J4, K3 and N3:	D-	Average - Forgings K4 and N4:	E
MA67	Average - Forgings J5, K5 and N5:	D-		
Visual Quality - End Cracking[2,3]				
MA65	Average - Forgings J1, J2, K1 and N1:	A-,E	Forging K2:	E
MA66	Average - Forgings J3, J4, K3 and N3:	B,E	Average - Forgings K4 and N4:	D-
MA67	Average - Forgings J5, K5 and N5:	D-,E		

Notes:
1 Percent Metal Recovery = 100 x Volume SNT Class A/1700 cu. in.
2. Visual Quality Ratings:

	FACES	ENDS
A	Practically perfect	Practically perfect
B	Slight tears	Surface tears
C	Slight checking	Slight checking
D	Checking, small cracks	Checking, small cracks
E	Medium, large cracks	Medium, large cracks, folds

3. Forging Code Number - Rating of one end, rating of other end.
4. Other processing conditions for these forgings given in Tables 78 and 82.

WSC:km 8-4-72

TABLE 60

EFFECT OF PREHEAT ATMOSPHERE AND TIME ON FORGING QUALITY OF
6.5 Zn-2.3 Mg-1.5 Cu ALLOY - 3" SQ. AND 5" SQ. HAND FORGINGS

Preheat Atmosphere[1]	Preheat Time (Hours)	Gas Flow Rate (CFH/lb)				Gas Flow Rate (CFH/lb)			
		0	0.17	0.35	0.75	0	0.17	0.35	0.75
Ultrasonic Quality - % Metal Recovery[2]									
Retort - Argon	1		86	90	89				
Retort - Purified Argon	1			89					
Retort - Argon	5			93					
Retort - Nitrogen	1			88	90				
Retort - Ambient Air	1	91							
Circulating Furnace Air	1	18							
Visual Quality - Face Cracking[3]		3" Square Forgings				5" Square Forgings			
Retort - Argon	1		B	B	B		B	B	A
Retort - Purified Argon	1			A				A	
Retort - Argon	5			A				A	
Retort - Nitrogen	1			A	A			A	A
Retort - Ambient Air	1	C				D-			
Circulating Furnace Air	1	E				E			
Visual Quality - End Cracking[3]		3" Square Forgings				5" Square Forgings			
Retort - Argon	1		B	D	A		A	A	A
Retort - Purified Argon	1			A				A	
Retort - Argon	5			A				A	
Retort - Nitrogen	1			A	A			A	A
Retort - Ambient Air	1	A				A			
Circulating Furnace Air	1	E				E			

Notes: 1. Other processing conditions for Forgings A1 to A13 listed in Table 55.

2. Percent Metal Recovery = $\frac{\text{Volume of SNT Class A Forgings}}{\text{Volume of Scalped Billet}} \times 100$

3. Visual Quality Ratings:

	FACES	ENDS
A	Practically perfect	Practically perfect
B	Slight tears	Surface tears
C	Slight checks	Surface checks
D	Checks, small cracks	Checks, small cracks
E	All severely cracked	Severe crack

WSC:dld
8/3/72

TABLE 61

EFFECT OF PREHEAT TEMPERATURE AND ATMOSPHERE ON METAL RECOVERY OF 6.5 Zn-2.3 Mg-1.5 Cu ALLOY - 3" SQ. AND 5" SQ. HAND FORGINGS

Preheat Atmosphere[1]	Preheat Temperature (°F) 950	1000	1050	Preheat Temperature (°F) 950	1000	1050
Ultrasonic Quality - % Metal Recovery[2]						
Argon	89	90	89			
Nitrogen	89	88	(4)			
Visual Quality - Face Cracking[3]						
	3" Square Forgings			5" Square Forgings		
Argon	B	B	A	B-	B	A
Nitrogen	A	A	(4)	A	A	(4)
Visual Quality - End Cracking[3]						
	3" Square Forgings			5" Square Forgings		
Argon	A	D	B	A	A	A
Nitrogen	A	A	(4)	A	A	(4)

Notes: 1. Retort preheat with gas flow of 0.35 CFH/lb. of compact. Other processing conditions in Table 55.

2. $$\text{Percent Metal Recovery} = \frac{\text{Volume of SNT Class A Forging}}{\text{Volume of Scalped Billet}} \times 100$$

3. Visual Quality Rating:

	FACES	ENDS
A	Practically perfect	Practically perfect
B	Slight tears	Surface tears
C	Slight checks	Surface checks
D	Checks, small cracks	Checks, small cracks
E	All severely cracked	Severe crack

4. Compact cracked while loading for hot press.

WSC:dld
8/3/72

Table 62

EFFECT OF HOT COMPACTING PRESSURE ON THE NUMBER OF ISOLATED DISCONTINUITIES IN 3" SQUARE AND 5" SQUARE HAND FORGINGS

Alloy	Hot Compacting Pressure (ksi)→	Number of Isolated Discontinuities		
		60	75	90
MA65: 6.5 Zn-2.3 Mg-1.5 Cu		8	12	4
MA66: 8.0 Zn-2.5 Mg-1.0 Cu		13	18	3
MA67: 8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co		12	15	1

Notes: 1. Compacts from 23μM powders.

2. Other processing conditions shown in Table 55 for Forgings B1 to B17.

WSC:km
8-3-72

TABLE 63

EFFECT OF THE AMOUNT OF SCALP ON METAL RECOVERY IN 6.5 Zn-2.3 Mg-1.5 Cu ALLOY - 5" SQ. HAND FORGINGS

Minimum Scalp		Scalp from Ram End of Forging					
		0	0.25"	1.0"	4.5"	8.0"	8.75"
		Scalp from Blind Die End of Forging					
From Diameter	Diameter	0	8.75"	8.0"	4.5"	1.0"	0.25"
Ultrasonic Quality - % Metal Recovery[1]							
0[2]	Tapered	49					
0.30"	8.25"				100		
0.55	8.0				100		
0.67	7.75		100	94	95	66	70
1.05	7.50				100		
Visual Quality - Face Cracking[3]							
0[2]	Tapered	E					
0.30"	8.25"				C		
0.55	8.0				B		
0.67	7.75		C-	C-	C	D	C
1.05	7.50				B		
Visual Quality - End Cracking[3]							
0[2]	Tapered	E					
0.30"	8.25"				B-		
0.55	8.0				A		
0.67	7.75		A	A	A	B	A
1.05	7.50				A		

Notes: 1. Percent Recovery = $\frac{\text{Volume of SNT Class A Forging}}{\text{Volume of Forging Billet}} \times 100$

2. Unscalped Forging Billet, 8.2" to 9.2" dia. X 28" long.

3. Visual Quality Ratings:

	FACE	ENDS
A	Practically perfect	Practically perfect
B	Slight tears	Surface tears
C	Slight checks	Surface checks
D	Checks, small cracks	Checks, small cracks
E	All severely cracked	Severe crack

4. See Table 55 for other processing conditions of Forgings C1 to C9.

WSC:dld
8/3/72

TABLE 64

ULTRASONIC QUALITY RATING OF 2.2" X 10" AND 5" X 10" HAND FORGINGS[1]

Alloy	Powder Size μM	2.2" X 10" X 47" Hand Forgings: Average Sound Forging Volume cu. in.	2.2" X 10" X 47" Hand Forgings: Average % Metal Recovery[2]	5" X 10" X 36" Forged Rolling Stock: Average Sound Forging Volume cu. in.	5" X 10" X 36" Forged Rolling Stock: Average % Metal Recovery
MA65: 6.5 Zn-2.3 Mg-1.5 Cu	15.6	799	80	822	48
	48.5	567	57	409	24
MA66: 8.0 Zn-2.5 Mg-1.0 Cu	16.5	798	80	648	38
	49.3	536	54	274	16
MA67: 8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co	14.7	831	84	728	43

Notes: 1. Other processing conditions in Tables 51, 78 and 82.

2. Percent Recovery = $\frac{\text{Volume of SNT Class "A" Forging}}{\text{Scalped Billet Volume} = 995 \text{ in.}^3} \times 100.$

3. Percent Recovery = $\frac{\text{Volume of SNT Class "A" Forging}}{\text{Unscalped Billet Volume} = 1700 \text{ in.}^3} \times 100.$

WSC:dld
8/3/72

Table 65

EFFECT OF INCREASING HOT WORK
ON QUALITY OF MA65 ALLOY HAND FORGINGS[3]

Section Size→	5" Sq. x 12"	3-1/2" Sq. x 21"	2" Sq. x 47"
Ultrasonic Quality			
% Metal Recovery[1]	100	100	100
Visual Quality[2]			
Face Cracking	A	A	A
End Cracking	A	A	A

Notes: 1. Percent Metal Recovery = $\frac{\text{Volume of Forging = SNT Class A}}{\text{Volume of Scalped Billet}}$ X 100

2. A = No cracking (a practically perfect forging).
3. Forging H1 (S-No 404877) from 15.6μM powder, cold pressed to 78% green density, preheated 2 hours @ 1000 F, hot pressed at 90 ksi, scalped to 7.5" dia. x 19" long, reheated to 700 F and A upset and draw forged to section sizes shown above.

WSC:km
8-3-72

Table 66

EFFECT OF PROCESS VARIATIONS ON OXYGEN CONTENT AND MECHANICAL PROPERTIES OF 3" SQUARE HAND FORGINGS

	PROCESS VARIATIONS									MECHANICAL PROPERTIES[8]														
			Preheat							Longitudinal					Long-Transverse					Short-Transverse				
Forging No.	Alloy[1]	Powder Size[2] μM	Method[3]	Time hrs	Temp. °F	Gas	Flow CFH/lb	Hot Compact Press ksi	Oxygen in Compact Wt. %	T.S. ksi	Y.S. ksi	% El	% RA	NTS/YS	T.S. ksi	Y.S. ksi	% El	% RA	NTS/YS	T.S. ksi	Y.S. ksi	% El	% RA	NTS/YS
404877A1	MA65	15.6	Retort	1.0	1000	Ar	0.17	90	0.28[10]	80.0	71.8	17.0	34	1.32	75.3	65.0	12.5	23	1.01	77.2	63.3	8.0	9	0.81
404877A2	MA65	15.6	Retort	1.3	1000	Ar	0.35	90	0.30	78.5	70.6	16.0	31	1.32	75.8	66.0	13.0	27	1.04	77.4[9]	65.8	7.0	10	0.91
404877A3	MA65	15.6	Retort	1.6	1000	Ar	0.75	90	0.31	77.8[9]	69.7	17.0	38	1.35	74.0	64.2	8.0	10	0.98	76.4	66.1	6.0	6	0.75
404877A4	MA65	15.6	Retort	5.0	1000	Ar	0.35	90	0.29	78.9	70.8	17.5	40	1.36	76.3[9]	64.6	12.0	18	1.02	77.0[9]	65.7	6.5	7	0.89
404877A5	MA65	15.6	Retort	1.7	1000	Ar	0.35	90	0.31	78.1[9]	69.3	16.5	32	1.36	75.6	65.6	12.0	18	1.03	76.5	66.9	7.0	12	0.87
404877A6	MA65	15.6	Retort	1.0	950	Ar	0.35	90	0.31	78.0	71.4	18.0	34	1.34	75.3	65.2	11.5	22	0.91	76.0	65.4	7.0	9	0.80
404877A7	MA65	15.6	Retort	1.0	1050	Ar	0.35	90	0.31	77.9	69.0	18.0	36	1.34	74.6	64.2	9.5	14	1.01	76.5	65.7	12.0	6	0.83
404877A8	MA65	15.6	Retort	1.3	1000	N_2	0.35	90	0.31	77.2	71.2	7.0	27	1.27	76.4	65.4	13.0	25	1.07	76.8	67.6	4.5	4	0.96
404877A9	MA65	15.6	Retort	1.0	1000	N_2	0.75	90	0.32	79.7	70.9	17.0	30	1.29	76.6	65.6	12.5	19	1.12	74.0	66.6	3.0	5	1.05
404877A10	MA65	15.6	Retort	1.3	950	N_2	0.35	90	0.31	77.0	68.6	11.5	33	1.34	75.3	64.2	10.0	7	1.02	71.2[9]	66.2	1.0	2	0.78
404877A12	MA65	15.6	Retort	[illegible]	1000	Air	None	90	0.32	82.7[9]	73.3	14.5	28	0.85	77.0	65.3	9.5	22	0.82	71.5[9]	66.6	1.5	0.5	0.36
404877A13	MA65	15.6	Furnace	1.1	1000	Air	(4)	90	0.32	(6)														
404877B1	MA65	15.6	Furnace	1.0	1000	Ar	0.29	90	0.32	78.4[9]	69.6	16.5	38	1.36	75.2[9]	64.2	11.5	16	0.99	73.9[9]	66.2	3.0	3	0.69
404878B2	MA65	23.9	Furnace	1.3	1000	Ar	0.29	60	0.22	81.8	74.0	13.0	24	1.24	75.8[9]	64.5	8.0	10	0.89	68.8[9]	66.4	1.0	1	0.57
404878B3	MA65	23.9	Furnace	1.5	1000	Ar	0.29	75	0.24	79.2	71.6	16.5	37	1.28	77.3	66.2	11.0	14	0.84	70.6[9]	63.3	2.0	2	0.54
404878B4	MA65	23.9	Furnace	1.8	1000	Ar	0.29	90	0.23	86.0	77.0	16.0	23	1.14	77.0	64.8	8.0	10	0.78	(7)				

Table 66 (Cont'd.)

EFFECT OF PROCESS VARIATIONS ON OXYGEN CONTENT AND MECHANICAL PROPERTIES OF 3" SQUARE HAND FORGINGS

	PROCESS VARIATIONS									MECHANICAL PROPERTIES[8]														
			Preheat							Longitudinal					Long-Transverse					Short-Transverse				
Forging No.	Alloy[1]	Powder Size[2] µM	Method[3]	Time hrs	Temp. °F	Gas	Flow CFH/lb	Hot Compact Press ksi	Oxygen in Compact Wt. %	T.S. ksi	Y.S. ksi	% El	% RA	NTS/YS	T.S. ksi	Y.S. ksi	% El	% RA	NTS/YS	T.S. ksi	Y.S. ksi	% El	% RA	NTS/YS
404879B5	MA65	48.3	Furnace	2.0	1000	Ar	0.29	90	0.054	(6)					(6)					(6)				
404881B6	MA66	16.5	Furnace	1.0	1000	Ar	0.29	90	0.30	86.5	80.4	15.0	29	1.14	80.1	70.3	6.0	5	0.77	77.3[9]	71.0	2.0	5	0.60
404881B7	MA66	21.8	Furnace	1.2	1000	Ar	0.29	60	0.25	86.3	81.3	14.0	31	0.94	82.4	72.8	8.0	11	0.64	(7)				
404881B8	MA66	21.8	Furnace	1.5	1000	Ar	0.29	75	0.22	86.6	81.3	14.0	29	0.93	82.8[9]	73.0	3.5	3	0.54	(7)				
404881B9	MA66	21.8	Furnace	1.7	1000	Ar	0.29	90	0.22	87.4	81.7	13.5	27	0.92	82.9[9]	73.3	5.0	4	0.59	78.5[9]	74.6	2.0	2	0.41
404882B10	MA66	49.3	Furnace	1.0	1000	Ar	0.29	90	0.052	(6)					(6)					(6)				
404883B11	MA67	14.7	Furnace	1.0	1000	Ar	0.29	60	0.27	87.4	80.0	12.5	30	0.89	84.3	73.6	7.0	9	0.55	81.6	75.4	1.0	3	0.47
404883B12	MA67	14.7	Furnace	1.3	1000	Ar	0.29	90	0.28	88.3	79.9	11.0	25	0.87	84.9	74.8	6.0	8	0.60	80.6	75.8	1.0	1	0.42
404884B13	MA67	22.7	Furnace	1.7	1000	Ar	0.29	60	0.24	88.5	80.2	12.0	27	0.84	81.6	72.8	2.0	2	0.62	74.4	73.5	1.0	0	0.33
404844B14	MA67	22.7	Furnace	2.0	1000	Ar	0.29	75	0.25	88.1	80.2	11.0	25	0.83	83.5	73.6	4.0	6	0.58	75.2	74.4	1.0	0	0.44
404844B15	MA67	22.7	Furnace	2.1	1000	Ar	0.29	90	0.24	92.0	94.4	12.5	22	0.74	86.9	75.6	5.0	8	0.46	(7)				

Notes:
1. See Table 5 for alloy compositions.
2. Average Particle Diameter, all air atomized powders.
3. All preheated in a muffle atmosphere furnace (except as noted) immediately before hot pressing.
4. Circulating air reheat furnace.
5. Argon purified by passing through a heated aluminum pellet bed.
6. Cracked in forging. Less than SNT Class A quality.
7. Forging cracked during aging orthagonal to short-transverse direction.
8. 3" square forgings heat treated @ 920 F for 2 hours, cold-water quenched, natural aged 4-7 days (retests 135 days) + 24 hrs @ 250 F.
9. Retested (tensile only). All M.T. 051071-K.
10. Analytical Chemistry J. O. 71-062910. Fast Neutron Activation Analysis. Samples 4" from ram end of 8.7" dia. x 28" long hot pressed compact, center line of compact orthagonal to center line of and bisecting length of 0.7" dia. x 2" long oxygen sample.

TABLE 67

EFFECT OF INCREASED REDUCTION ON TENSILE AND NOTCHED TENSILE PROPERTIES OF MA65[1] ALLOY HAND FORGINGS

Direction	L Ratio[2]	Mechanical Properties[3]: T.S. ksi	Y.S. ksi	El % in 4D	R. of A. %	NTS ksi	NTS/YS	Approximate K_{Ic}[5] ksi√in.
Longitudinal	5	82.8	75.6	16.4	34	95.6	1.27	27
	10.2	80.0	73.6	16.4	41	95.1	1.29	27
	31	79.1	71.8	17.2	45	95.7	1.33	29
Long-Transverse	5	82.1	70.8	12.5	16	56.9	0.80	15
	10.2	81.0	71.6	12.1	18	69.5	0.97	18
	31	79.1	70.0	10.2	15	75.9	1.08	21
Short-Transverse	5	76.6	68.7	3.1	2	45.0	0.65	13
	10.2	81.4	70.6	8.6	10	56.0	0.79	15
	31	79.2	72.1	6.2	10	73.2	1.02	19

Notes:

1. Sample 404877-H1, Al-6.4 Zn-2.5 Mg-1.5 Cu, from 15.6 μM powder cold pressed isostatically at 30 ksi, preheated 2 hours @ 1000 F in argon, hot pressed at 90 ksi, scalped to 7.5" dia. X 19" long, reheated to 700 F and A upset and draw forged to 5" sq., stepped to 3-1/2" sq., stepped to 2" sq.

2. $L = \frac{\text{Cross Sectional Area of Billet}}{\text{Cross Sectional Area of Forging}}$; 5" sq. (L=5); 3 1/2" sq. (L=10.2); 2" sq. (L=31).

3. From M.T. No. 051071-F, dated 7-22-71 or 8-24-71.

4. All samples solution heat treated as 1" sq. blanks X 5", 4", 3-1/2", 3", or 2" long @ 920 F for 2 hours cold-water quenched, aged 7 days at room temperature + 24 hours @ 250 F.

5. See Figure 10 (from Ref. 5).

WSC:dld
8/3/72

TABLE 68

EFFECT OF ALLOY AND POWDER SIZE ON MECHANICAL PROPERTIES OF 3" SQUARE HAND FORGINGS

Alloy	Composition				Longitudinal Properties Powder Size[5]			Long-Transverse Properties Powder Size[5]			Short-Transverse Properties Powder Size[5]		
	Zn	Mg	Cu	Co	15	23	50	15	23	50	15	23	50
Yield Strength (ksi)													
MA65	6.4	2.3	1.5		69.6	77.0	(3)	64.2	64.8	(3)	66.2	(2)	(3)
MA66	8.1	2.5	1.1		80.4	81.7	(3)	70.3	73.3	(3)	71.0	74.6	(3)
MA67	8.0	2.5	1.0	1.6	79.9	84.4	(4)	74.8	75.6	(4)	75.8	(2)	(4)
Elongation (% in 4D)													
MA65	6.4	2.3	1.5		16.5	16.0	(3)	11.5	8.0	(3)	3.0	(2)	(3)
MA66	8.1	2.5	1.1		15.0	13.5	(3)	6.0	5.0	(3)	2.0	2.0	(3)
MA67	8.0	2.5	1.0	1.6	11.0	12.5	(4)	6.0	5.0	(4)	1.0	(2)	(4)
NTS/YS													
MA65	6.4	2.3	1.5		1.36	1.14	(3)	0.99	0.78	(3)	0.69	(2)	(3)
MA66	8.1	2.5	1.1		1.14	0.92	(3)	0.77	0.59	(3)	0.60	0.41	(3)
MA67	8.0	2.5	1.0	1.6	0.87	0.74	(4)	0.60	0.46	(4)	0.42	(2)	(4)

Notes:
1. All forgings from compacts hot pressed at 90 ksi (other fabricating conditions in Table 55), heat treated as 3" sq., aged to T6 temper.
2. Forging cracked orthagonal to short-transverse direction during aging.
3. Forging would not meet ultrasonic SNT Class A quality standards.
4. No forging prepared.
5. Average Particle Diameter in μM.

WSC:dld
8/3/72

Table 69

EFFECT OF PREHEAT ATMOSPHERE AND TIME ON NOTCHED TENSILE STRENGTH:YIELD STRENGTH RATIO OF 3" SQUARE HAND FORGINGS FROM FINE POWDER MA65 ALLOY[4]

Atmosphere	Preheat Time[3]	Longitudinal NTS/YS Gas Flow Rate (CFH/lb)				Long-Transverse NTS/YS Gas Flow Rate (CFH/lb)				Short-Transverse NTS/YS Gas Flow Rate (CFH/lb)			
	Hours	0	0.17	0.35	0.75	0	0.17	0.35	0.75	0	0.17	0.35	0.75
Retort: Argon	1		1.32	1.32	1.35		1.01	1.04	0.98		0.81	0.91	0.75
Retort: Argon	5			1.36				1.02				0.89	
Retort: Purified Argon	1			1.36				1.03				0.87	
Retort: N_2	1			1.27	1.29			1.07	1.12			0.96	1.05
Retort: Ambient Air	1	0.85				0.82				0.36			
Circulating Air	1	(1)				(1)				(1)			
Furnace Argon[2]	1			1.36				0.99				0.69	

Notes:
1. Forging less than SNT Class A quality - cracked during forging.
2. Preheated with 0.29 CFH/lb flow rate in an atmosphere furnace. Forging 404877B1 exposed to no door openings prior to its being removed from furnace.
3. Other fabricating conditions shown in Table 55.
4. 15.6μM Average Particle Diameter Powder in Al-6.5 Zn-2.3 Mg-1.5 Cu Alloy.

WSC:km
8-4-72

TABLE 70

EFFECT OF PREHEAT TIME AND ATMOSPHERE ON ELONGATION OF 3" SQ. HAND FORGINGS FROM FINE POWDER MA65 ALLOY[8]

Atmosphere[2]	Preheat Time[7]	Elongation - % in 4D: Longitudinal Gas Flow Rate (CFH/lb)				Long-Transverse Gas Flow Rate (CFH/lb)				Short-Transverse Gas Flow Rate (CFH/lb)			
	Hours	0	0.17	0.35	0.75	0	0.17	0.35	0.75	0	0.17	0.35	0.75
Retort: Argon	1		17	16[4]	17		13	13[4]	8		8[4]	7	6
Retort: Argon	5			18				12				6	
Retort: Purified Argon	1			16				12				7[4]	
Retort: Nitrogen	1			14[4]	17			13	13			5	3
Retort: Ambient Air	1	14				10				2			
Circulating Air	1	([1])				([1])				([1])			
Furnace: Argon[3]	1			16				12				3	

Notes:
1. Forging too severely cracked for testing.
2. All compacts preheated at 1000 F under conditions shown.
3. Preheated with 0.29 CFH/lb flow rate. Exposed to no door openings prior to removal from the furnace.
4. Single specimen, all others average of duplicate tests.
5. Failed outside gauge length.
6. Retest being made.
7. Other fabricating conditions in Table 55.
8. Al-6.5 Zn-2.3 Mg-1.5 Cu in 15.6 μM Average Particle Diameter Powder.

WSC:dld
3/3/72

TABLE 71

EFFECT OF PREHEAT TIME AND ATMOSPHERE ON REDUCTION OF AREA OF 3" SQ. HAND FORGINGS FROM FINE POWDER MA65 ALLOY[8]

Atmosphere[2]	Preheat Time[7]	Reduction in Area - % Longitudinal Gas Flow Rate (CFH/lb)				Long-Transverse Gas Flow Rate (CFH/lb)				Short-Transverse Gas Flow Rate (CFH/lb)			
	Hours	0	0.17	0.35	0.75	0	0.17	0.35	0.75	0	0.17	0.35	0.75
Retort: Argon	1		34	31	38		23	27[4]	10		17[4]	10	6
Retort: Argon	5			40				18				7	
Retort: Purified Argon	1			32				18				12	
Retort: Nitrogen	1			27[4]	30			25	19			4	8[4]
Retort: Ambient Air	1	30				22				1			
Circulating Air	1	([1])				([1])				([1])			
Furnace: Argon[3]				38				16				3	

Notes:
1. Forging too severely cracked for testing.
2. All compacts preheated at 1000 F under conditions shown.
3. Preheated with 0.29 CFH/lb flow rate, exposed to no door openings prior to removal from the atmosphere furnace.
4. Single specimen, all others average of duplicate tests.
5. Failed outside gauge length.
6. Retest being made.
7. Other fabricating conditions in Table 55.
8. Al-6.5 Zn-2.3 Mg-1.5 Cu in 15.6 μM average particle diameter powder.

WSC:dld
8/3/72

Table 72

EFFECT OF PREHEAT GAS ON DISSOLVED GAS IN P/M HAND FORGINGS

Sample No.	Preheat Method[1]	Preheat Gas	Gas Flow[2] CFH/lb	Total Gas[3] ml/100 gm	Gas Compositions[5] - %				Total Nitrogen[4]
					H_2	Ar	N_2	Others	
404877-A3	RET	Argon	0.75	14.6	97.8	0.2	1.9	0.1	0.06%
404877-A9	RET	Nitrogen	0.75	3.0	99.3	0.0	0.6	0.1	0.14%

Notes:
1. Retort preheat - Figure 24.
2. Cubic feet per hour per lb. of compact.
3. Total detected gas in 700 C fusion extraction per 100 grams of sample.
4. Nitrogen present in solid and gaseous forms in the wrought product.
5. Analytical Chemistry J.O. 71-111608.

WSC:km
8-3-72

Table 73

EFFECT OF PREHEAT ATMOSPHERE ON MECHANICAL PROPERTIES OF 3" SQUARE HAND FORGINGS FROM FINE POWDER MA65 ALLOY[2]

Preheat Gas[1]	Gas Flow Rate CFH/lb.	Forging Density lbs/in.^{3}	Total Gas Content ml/100gms	Longitudinal			Long-Transverse			Short-Transverse		
				Y.S. ksi	% El.	NTS/YS	Y.S. ksi	% El.	NTS/YS	Y.S. ksi	% El.	NTS/YS
Nitrogen	0.75	0.1023	3.0	70.9	17	1.29	65.6	13	1.12	66.6	3	1.05
Argon	0.75	0.1023	14.6	69.7	17	1.35	64.2	8	0.98	66.1	6	0.75

Notes: 1. Preheated in a retort for one hour @ 1000 F immediately before hot pressing.

2. Al-6.5 Zn-2.3 Mg-1.5 Cu alloy from a 15.6 μM Average Particle Diameter Powder.

WSC/lmk
9/26/72

Table 74

EFFECT OF SAMPLE LOCATION ON OXYGEN CONTENT OF AN ARGON ATMOSPHERE FURNACE PREHEATED MA65 ALLOY COMPACT AFTER HOT PRESSING

S-No.[2]	Distance[1] - Compact Surface to Specimen Center Line	Weight Per Cent Oxygen[4]
404877 C2-1R	0.7"	0.40
404877 C2-2R	1.5"	0.33
404877 C2-3R	2.5"	0.30
404877 C2-4R	4.0"	0.29
404877 C2-5R	8.0"	0.29

Notes:
1. Distance from "ram" end of hot pressed compact. Compact is 8.4" diameter on ram end, tapering to 9.2" diameter over 28" length. See Figure 2.
2. Al-6.5 Zn-2.3 Mg-1.5 Cu alloy from 15.6μM air atomized powder.
3. Analytical Chemistry J.O. 71-062910.
4. Compact exposed to one door opening - closing cycle before removal from atmosphere furnace. Other fabricating conditions in Table 55.

WSC:km
8-3-72

TABLE 75

EFFECT OF PREHEAT ATMOSPHERE AND TEMPERATURE ON FRACTURE TOUGHNESS (NTS/YS) AND DUCTILITY OF 3" SQUARE HAND FORGINGS FROM FINE POWDER MA65 ALLOY[3]

Atmosphere	Longitudinal Preheat Temperature (°F)			Long-Transverse Preheat Temperature (°F)			Short-Transverse Preheat temperature (°F)		
	950	1000	1050	950	1000	1050	950	1000	1050
Notched Tensile Strength/Yield Strength									
Nitrogen	1.34	1.27	(1)	1.02	1.07	(1)	0.78	0.95	(1)
Argon	1.34	1.32	1.34	0.91	1.04	1.01	0.80	0.91	0.83
Elongation (% in 4D)									
Nitrogen	12	7[2]	(1)	10	13	(1)	1	5	(1)
Argon	18	16	18	12	13	10	7	7	12
Reduction in Area (%)									
Nitrogen	33	27	(1)	7	25	(1)	2	4	(1)
Argon	34	31	36	22	27	12	9	10	6

Notes:
1. Cracked in loading for hot pressing.
2. Failed outside gauge length.
3. Other fabricating conditions in Table 55 for this Al-6.5 Zn-2.3 Mg-1.5 Cu alloy from a 15.6 μM APD powder.

WSC:dld
8/3/72

TABLE 76

EFFECT OF HOT COMPACTING PRESSURE AND ALLOY ON PROPERTIES OF P/M 3" SQUARE HAND FORGINGS[1]

Alloy[3]	Longitudinal Hot Compacting Pressure (ksi) 60	75	90	Long-Transverse Hot Compacting Pressure (ksi) 60	75	90	Short-Transverse Hot Compacting Pressure (ksi) 60	75	90
Yield Strength (ksi)									
MA65	74.0	71.6	77.0	64.5	66.2	64.8	66.4	63.3	(2)
MA66	81.3	81.3	81.7	72.8	73.0	73.3	(2)	(2)	74.6
MA67	80.2	80.2	84.4	72.8	73.6	75.6	73.5	74.4	(2)
Elongation (% in 4D)									
MA65	13.0	16.5	16.0	8.0	11.0	8.0	1.0	2.0	(2)
MA66	14.0	14.0	13.5	8.0	3.5	5.0	(2)	(2)	2.0
MA67	12.0	11.0	12.5	2.0	4.0	5.0	1.0	1.0	(2)
Reduction of Area (%)									
MA65	24	37	23	10	14	10	1	2	(2)
MA66	31	29	27	11	3	4	(2)	(2)	2
MA67	27	25	22	2	6	8	0	0	(2)
Notched Tensile Strength/Yield Strength									
MA65	1.24	1.28	1.14	0.89	0.84	0.78	0.57	0.54	(2)
MA66	0.94	0.93	0.92	0.64	0.54	0.59	(2)	(2)	0.41
MA67	0.84	0.83	0.74	0.62	0.58	0.46	0.33	0.44	(2)

Notes:
1. Forgings from 23 μM powder heat treated as 3" square bar, aged to T6 temper. Other fabricating conditions in Table 55.
2. No tests - quench crack orthagonal to short-transverse direction.
3. Compositions in Table 5.

WSC:dld
8/3/72

TABLE 77

EFFECT OF ATMOSPHERE FURNACE DOOR OPENINGS, PREHEAT TIME, HOT COMPACTING PRESSURE AND ALLOY ON OXYGEN CONTENT OF P/M COMPACTS[2]

Alloy[5]	Hot Compacting Pressure[4] 60 ksi	75 ksi	90 ksi
Prior Door Openings[1]			
MA65	1	2	3
MA66	1	2	3
MA67	2	3	4
Preheat Time (Hours)			
MA65	1.3	1.5	1.8
MA66	1.2	1.5	1.7
MA67	1.7	2.0	2.1
Weight Percent Oxygen[3]			
MA65	0.22	0.24	0.23
MA66	0.25	0.22	0.22
MA67	0.24	0.25	0.24

Notes:
1. Door openings prior to opening for removal from furnace for hot pressing.
2. All compacts from 23 uM powders
3. Analytical Chemistry J. O. 71-062910.
4. Other fabricating conditions in Table 55 .
5. Compositions in Table 5.

WSC:dld
8/3/72

Table 78

PROCESS CONDITIONS FOR COMPACTS TO BE FABRICATED TO PLATE

Sample No.	Powder Size[1] μM	Approx. Cold Compact Density[2] %	Preheat Conditions: Method[3]	Preheat Conditions: Time hrs	Preheat Conditions: Temp °F	Preheat Conditions: Gas	Preheat Conditions: Flow CFH/lb	Hot Compact Pressure ksi	Scalped Billet[4]: Dia. in.	Scalped Billet[4]: Length[5] in.
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu										
404877-K1	15.6	78	Furnace	1.3	1000	Argon	0.29	90	Unscalped	
404877-N1	15.6	78	Furnace	1.6	1000	Argon	0.29	90	Unscalped	
404877-J1	15.6	78	Furnace	2.1	1000	Argon	0.29	90	Unscalped	
404877-P8[6]	15.6	78	Furnace	24	1000	Argon	0.29	90	7.5	22.5
404879-X6[6]	48.5	80	Furnace	24	1000	Argon	0.29	90	7.5	22.5
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu										
404880-N3	16.5	78	Furnace	2.2	1000	Argon	0.29	90	Unscalped	
404880-J4	16.5	78	Furnace	1.5	1000	Argon	0.29	90	Unscalped	
404880-K3	16.5	78	Furnace	1.2	1000	Argon	0.29	90	Unscalped	
404882-K4	49.3	76	Furnace	1.5	1000	Argon	0.29	90	Unscalped	
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co										
404883-J5	14.7	76	Furnace	1.5	1000	Argon	0.29	90	Unscalped	
404883-N5	14.7	76	Furnace	1.6	1000	Argon	0.29	90	Unscalped	

Notes:
1. Average Particle Diameter from Fisher Sub-Sieve Sizer.
2. Percent of Theoretical - from Table 9.
3. Preheated in a muffle atmosphere furnace immediately before hot pressing.
4. Hot pressed compact: 8.3" to 9.2" diameter (tapered) x 28" long.
5. Equal amounts scalped from each end of hot pressed billet.
6. Forged to 5" x 10" x 24" slab.

WSC:km
8-8-72

Table 79

SCALPING OF 5" x 10" x 35" PREFORGED ROLLING STOCK FOR PLATE

Alloy	S. No.	Piece Number	Powder Size[1] μM	Amount Scalped: Ram Face	Amount Scalped: Blind Die Face	Amount Scalped: Edges	Scalped Slab Dimensions
Stock for 1.5" Thick Plate							
MA65	404877	K1	15.6	0.75"	1.00"	3/4",3/4"	3-1/4" x 8-1/2" x 31"
	404877	N1	15.6	0.875"	0.975"	3/4",13/16"	3-1/4" x 8-7/8" x 30"
MA66	404880	N3	16.5	0.75"	1.00"	1",5/8"	3-1/4" x 8-3/8" x 30-5/8"
MA67	404883	J5	14.7	0.5"	1.25"	1",3/4"	3-1/4" x 8-1/4" x 31-7/8"

NOTE: 1. Average Particle Diameter from Fisher Sub-Sieve Sizer.

WSC/lmk
9/26/72

Table 80

TENSILE PROPERTIES OF P/M 1.5" THICK PLATE

Sample No.	Powder Size[1] µM	Preheat Atmosphere[2]	Quench Water Temp. °F	% Stretch	Second-Step Age[3] @ 325°F	Electrical Conductivity % IACS	Longitudinal Properties T.S. ksi	Longitudinal Y.S. ksi	Longitudinal El. % in 4D	Longitudinal R of A %	Longitudinal NTS/YS	Long-Transverse Properties T.S. ksi	Long-Transverse Y.S. ksi	Long-Transverse El. % in 4D	Long-Transverse R of A %	Long-Transverse NTS/YS	Short-Transverse Properties T.S. ksi	Short-Transverse Y.S. ksi	Short-Transverse El. % in 4D	Short-Transverse R of A %
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu																				
404877K1B	15.6	Argon	80	1.5	None	34.2	79.4	73.2	10.0	17	1.26	81.6	71.6	10.5	14	1.07	79.4	67.6	3.1	8
404877K1C	15.6	Argon	80	1.5	4 hrs.	40.7	75.6	69.6	12.0	22	1.24	77.7	69.6	9.2	16	1.09	71.4	68.3	(4)	0.5
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu																				
404880N3A	16.5	Argon	80	2.2	None	33.9	89.8	85.5	10.0	--	0.83	87.6	80.3	11.2	19	0.86	85.4	77.2	1.6	0.5
404880N3B	16.5	Argon	80	2.2	2 hrs.	39.0	83.8	79.1	10.5	16	0.99	82.2	76.3	11.5	26	0.91	84.5	76.3	6.3	6
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co																				
404883J5A	14.7	Argon	80	1.9	None	33.7	93.2	88.4	7.5	--	0.66	90.0	81.0	3.5	--	0.70	88.1	78.0	3.1	0
404883J5B	14.7	Argon	80	1.9	2 hrs.	36.0	83.8	77.3	9.2	14	0.84	84.9	76.4	9.0	15	0.82	82.4	75.4	0	0
7075 Alloy: Al-5.7 Zn-2.6 Mg-1.8 Cu-0.2 Cr (2.5" Thick)																				
399479	I/M[5]	--	80	1.5-5	None	30.8	86.4	79.8	16			87.5	77.6	12			76.0	65.6	3.0	
399480	I/M	--	80	1.5-5	10	36.6	73.5	63.8	14			76.0	64.2	9			72.0	61.8	4.0	
399481	I/M	--	80	1.5-5	24	39.8	69.9	59.3	15			72.3	60.6	10			68.8	58.9	4.0	

Notes:
1. Average Particle Diameter.
2. Isostatically pressed 170 lb green compacts preheated to 1000 F in flowing argon, hot pressed at 90 ksi, reheated, forged to 5"x10"x36", scalped to 3-1/4"x8-1/2"x31", reheated, hot rolled to 1.5" thick.
3. P/M 1.5" plate solution heat treated 2 hours @ 920 F, cold water quenched, stretched amount shown, aged 4-7 days at room temperature + 24 hours @ 250 F + further aging @ 325 F as shown.
4. Specimens failed outside gauge length.
5. I/M = Ingot Metallurgy. Production 7075-T651 2.5" thick plate purchased for comparison material. Samples laboratory second-step aged as indicated.

WSC:slo
8/21/72

Table 81

ALTERNATE IMMERSION STRESS-CORROSION PERFORMANCE OF P/M 1.5" PLATE.
SHORT-TRANSVERSE TENSILE BARS TESTED IN A.I. BY FEDERAL TEST METHOD 823.

Sample No.[1]	Second-Step Age[2] @ 325 F	Plate Properties LYS ksi	Plate Properties STYS ksi	Days to Failure at Indicated Stress Level in A.I. Test 25 ksi	30 ksi	35 ksi	40 ksi	45 ksi
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu								
404877-K1B	None	73.2	67.6	2,2,3	2,2,2	2,2,2	2,2,2	2,2,2
404877-K1C	4 hrs.	69.6	68.3	32,40,76	63,83,P[3]	32,45,59	31,32,45	31,31,68
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu								
404880-N3A	None	85.5	77.2	16,16,22	9,16,21	7,8,16	4,5,5	5,6
404880-N3B	2 hrs.	79.1	76.3	16,17,57	16,31,31	16,21,25	10,16,19	9,19,21
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co								
404883-J5A	None	88.4	78.0	2,3,P[3]	3,16,P[3]	1,1,3	2,2,3	2,2,2
404883-J5B	2 hrs.	77.3	75.4	P[3],P,P	P,P,P	27,38,84	2,3,8	9,24,32
I/M 7075 Alloy[4]								
399479-B[5]	None	79.8	65.6	2,2,2,2,2	2,2,2,3,3	2,2,2,2,2	2,2,2,2,3	2,2,2,2,5
399480-4	10 hrs.	63.8	61.8	59,67	36,37	28,48	29,31	8,36
399481-R[6]	24 hrs.	59.3	58.9	P,P,P,P,P	P,P,P,P,P	66,P,P,P,P	P,P,P,P,P	76,P,P,P,P

Notes:
1. All P/M plate from 15μM APD Powders.
2. First-step aged 24 hours @ 250 F.
3. P = pass 84 days exposure in A.I. with specimen intact.
4. 2.5" thick plate produced plate, 7075-T651, laboratory second-step aged.
5. Includes samples marked 413364-B.
6. Includes samples marked 413363-R.

WSC/lmk
8/11/72

Table 82

PROCESS CONDITIONS FOR COMPACTS TO BE FABRICATED TO SHEET

Sample No.	Powder Size µM	Approx. Cold Compact Density[2] %	Preheat Conditions Method[3]	Time hrs	Temp °F	Gas	Flow CFH/lb	Hot Compact Pressure ksi	Scalped Billet[4] Dia. in.	Length in.
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu										
404877-J2	15.6	78	Furnace	1.0	1000	Argon	0.29	90	Unscalped	
404879-K2	48.5	80	Furnace	1.0	1000	Argon	0.29	90	Unscalped	
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu										
404880-J3	16.5	78	Furnace	1.2	1000	Argon	0.29	90	Unscalped	
404882-N4	49.3	76	Furnace	1.9	1000	Argon	0.29	90	Unscalped	
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co										
404883-K5	14.7	76	Furnace	1.9	1000	Argon	0.29	90	Unscalped	

Notes:
1. Average Particle Diameter.
2. Percent of theoretical density - from Table 9.
3. Preheated in a muffle atmosphere furnace immediately before hot pressing.
4. Hot Pressed Compact: 8.3" to 9.2" diameter (tapered) x 28" long.

WSC:km
8-8-72

Table 83

SCALPING OF 5" x 10" x 35" PREFORGED ROLLING STOCK FOR SHEET

Alloy	S. No.	Piece Number	Powder Size[1] µM	Amount Scalped: Ram Face	Amount Scalped: Blind Die Face	Amount Scalped: Edges	Scalped Slab Dimensions
Stock for Rolling Sheet							
MA65	404877	J2	16	1.5"	1.5"	1-1/2",5/8"	2" x 7-1/2" x 24"
	404879	K2	48	1.5"	1.625"	1-3/4",1-5/16"	1-7/8" x 7-1/8" x 24"
MA66	404880	J3	16	1.625"	1.375"	1",15/16"	2" x 7-1/2" x 24"
	404882	N4	49	1.5"	1.5"	1-5/16",1-1/8"	2" x 7-1/2" x 24"
MA67	404883	K5	15	1.5"	1.5"	1-9/16",15/16"	2" x 7-1/2" x 24"

NOTE: 1. Average Particle Diameter from Fisher Sub Sieve Sizer.

WSC/lmk
9/26/72

Table 84

MECHANICAL PROPERTIES OF P/M 0.090" SHEET

							Longitudinal Properties						Transverse Properties					
Sample No.	Powder Size[1] μM	Preheat Atmosphere[2]	Quench Water Temp. °F	% Stretch	Second-Step Age[3] @ 325°F	Electrical Conductivity % IACS	T.S. ksi	Y.S. ksi	El. % in 2"	Tear Strength ksi	Tr.S./Y.S.	Unit Propagation Energy in.-lbs/in²	T.S. ksi	Y.S. ksi	El. % in 2"	Tear Strength ksi	Tr.S./Y.S.	Unit Propagation Energy in.-lbs/in²
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu																		
404877J2B	15.6	Argon	80	1.8	None	34.3	81.6	74.6	13.5	76.9	1.03	300	81.0	71.1	13.5	71.9	1.01	285
404879K2B	48.5	Argon	80	1.8	None	32.7	84.6	77.8	14.0	80.0	1.03	250	82.1	70.9	14.8	76.4	1.08	345
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu																		
404880J3B	16.5	Argon	80	1.8	None	33.5	87.2	83.2	11.5	59.0	0.71	100	86.3	78.4	11.0	56.8	0.72	100
404882N4B	49.3	Argon	80	1.8	None	31.5	90.8	86.8	11.5	56.4	0.65	195	88.6	79.4	11.2	53.6	0.67	170
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co																		
404883K5B	14.7	Argon	80	1.8	None	31.5	92.0	88.2	10.0	46.8	0.53	75	91.8	82.0	10.0	46.6	0.57	135
I/M 7075-T6 Sheet[4]							82.3	74.9	11.2	76.1	1.02	290	82.3	72.5	10.8	71.3	0.98	220
I/M 7050 Sheet[5]							85.6	79.0	11.0		1.17	(6)	85.8	79.1	11.0		1.12	300

Notes:
1. Average Particle Diameter.
2. Isostatically pressed 170 lb. green compacts preheated in flowing argon to 1000 F, hot pressed @ 90 ksi. Billet reheated, forged to 5"x10"x36" slab. Slab scalped to 2"x7.5"x24", hot rolled (cross rolled + longitudinally rolled) to 0.250", reheated, hot rolled to 0.144" thick, annealed, cold rolled to 0.090".
3. Sheet solution heat treated 1 hour @ 920 F, cold water quenched, stretched as shown, naturally aged 5 days + 24 hours @ 250 F.
4. Ref. 19.
5. Ref. 20.
6. Diagonal fractures.

BC:slo
/22/72

Table 85

EFFECT OF SECOND-STEP AGE TIME AT 325 F ON LONGITUDINAL TENSILE PROPERTIES OF P/M 0.090" SHEET

Sample No.	Powder Size[1] μM	Second-Step Age[2] @ 325°F	Longitudinal Properties T.S. ksi	Y.S. ksi	% El. in 1 in.
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu					
404877-J2B	15.6	None	80.7	73.5	13.5
404877-J2C	15.6	2 hrs.	82.2	77.2	12.0
404877-J2D	15.6	6 hrs.	80.6	75.2	11.5
404877-J2E	15.6	15 hrs.	77.6	69.2	11.0
404877-J2F	15.6	20 hrs.	73.2	64.2	12.5
404879-K2B	48.5	None	83.0	76.7	13.0
404879-K2C	48.5	2 hrs.	84.4	80.1	11.0
404879-K2D	48.5	6 hrs.	84.0	79.0	10.0
404879-K2E	48.5	15 hrs.	80.3	73.5	11.5
404879-K2F	48.5	20 hrs.	78.7	70.9	11.5
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu					
404880-J3B	16.5	None	86.0	82.7	12.0
404880-J3C	16.5	2 hrs.	84.5	82.6	10.5
404880-J3D	16.5	6 hrs.	81.0	76.6	11.0
404880-J3E	16.5	15 hrs.	76.8	69.5	12.0
404880-J3F	16.5	20 hrs.	74.4	65.6	12.0
404882-N3B	49.3	None	88.8	84.6	10.5
404882-N3C	49.3	2 hrs.	88.6	86.2	7.5
404882-N3D	49.3	6 hrs.	85.8	81.6	9.0
404882-N3E	49.3	15 hrs.	81.4	74.5	10.0
404882-N3F	49.3	20 hrs.	78.5	70.5	10.5
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co					
404883-K5B	14.7	None	89.4	84.7	9.0
404883-K5C	14.7	2 hrs.	86.6	81.4	9.0
404883-K5D	14.7	6 hrs.	82.8	75.6	10.0
404883-K5E	14.7	15 hrs.	76.6	66.8	11.0
404883-K5F	14.7	20 hrs.	73.2	62.2	11.0

Notes: 1. Average particle diameter.
2. First-step aged 24 hours @ 250 F.

WSC/lmk
8/11/72

Table 86

EFFECT OF ANNEALING TEMPERATURE ON GRAIN SIZE
IN P/M 0.090" SHEET

Sample No.	Alloy	Powder Size[1] μM	Grain Count (grains/mm³) Annealing Temperature (°F)[2] 700	750	800	850	920[5]	920[6]
404877 - J2	MA65	15.6	1,500	5,300	6,000	3,500	5,376	13,800
404879 - K2	MA65	48.5	40,300	62,900	69,400	37,000	55,080	49,900
404880 - J3	MA66	16.5	3,900	6,000	7,700	3,000	15,120	2,400
404882 - N4	MA66	49.3	23,200	62,600	115,500	42,200	88,536	59,600
404883 - K5	MA67	14.7	600	3,200[4]	6,900[4]	3,200	90,440	3,200

Notes:
1. Average Particle Diameter.
2. Samples annealed 1 hour @ 500, 600 and 650 F were partially recrystallized. Others annealed 1 hour at temperatures shown.
3. 0.090" sheet annealed in a hot HOMO furnace after cold rolling from 0.144" thick.
4. All samples are interior (₤) grain size. These samples showed much finer grain size near surface (to 1/3 of thickness from each side) - 48,000 grains/mm³ @ 750 F and 154,900 grains/mm³ @ 800 F.
5. One hour at 920 F, the solution heat treatment temperature used for this material, which was also sampled for tensile and tear properties in a maximum strength temper. Not separately annealed before SHT.
6. Annealed 2 hours @ 920 F.

WSC:km
8-7-72

Table 87

PROPERTIES OF ANNEALED P/M 0.090" SHEET

Sample No.	Powder Size[1] μM	Longitudinal[2] T.S. ksi	Longitudinal[2] Y.S. ksi	Longitudinal[2] % El in 2 in.	Transverse[3] T.S. ksi	Transverse[3] Y.S. ksi	Transverse[3] % El in 2 in.	45° to Rolling Direction T.S. ksi	45° to Rolling Direction Y.S. ksi	45° to Rolling Direction % El in 2 in.
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu										
404877-J2A	15.6	28.6	12.9	22.5	28.8	13.1	21.0	28.7	12.5	21.5
404879-K2A	48.5	28.2	10.0	23.0	28.0	10.8	23.0	27.6	9.6	24.5
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu										
404880-J3A	16.5	28.2	11.9	23.0	28.0	12.1	22.0	28.4	12.0	22.5
404882-N4A	49.3	27.6	9.8	25.0	27.3	10.7	23.5	27.0	9.6	26.0
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co										
404883-K5A	14.7	31.0	13.4	21.0	32.4	14.0	22.0	32.9	14.0	21.0
Commercial I/M 7075 Alloy										
Typical[4]					33	15	17			
Limits[5]					40 max	21 max	10 max			

Notes:
1. Average Particle Diameter.
2. Specimens at 0° to Rolling Direction.
3. Specimens at 90° to Rolling Direction.
4. From Ref. 21, Table 2.1.
5. From Ref. 21, Table 7.2.

WSC:km
8-7-72

Table 88

STRAIN HARDENING COEFFICIENT AND STRAIN RATIO FOR P/M SHEET

Sample No.	Powder Size[1] μM	Strain Hardening Coefficient[2] 0°	45°	90°	$\bar{n}$	Strain Ratio[3] 0°	45°	90°	$\bar{R}$
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu									
404877-J2A	15.6	.140	.146	.163	.149	.549	.626	.548	.589
404879-K2A	48.5	.202	.207	.201	.204	.559	.830	.515	.684
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu									
404880-J3A	16.5	.164	.160	.164	.162	.530	.590	.492	.550
404882-N4A	49.3	.200	.210	.210	.208	.576	.817	.508	.679
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co									
404883-K5A	14.7	.158	.172	.161	.166	.525	.518	.639	.550

Notes:
1. Average Particle Diameter.
2. n in $\sigma = \varepsilon^n$ from Ref. 17 at indicated degrees to rolling direction.

$$\bar{n} = \frac{n_0 + 2n_{45} + n_{90}}{4}$$

3. $R = \dfrac{\text{width strain}}{\text{thickness strain}}$ from Ref. 18 at indicated degrees to rolling direction.

$$\bar{R} = \frac{R_0 + 2R_{45} + R_{90}}{4}$$

.SC:km
3-7-72

Table 89

EXCO EXFOLIATION TEST RESULTS ON P/M 0.090" SHEET

Sample Number	Powder Size[1] μM	Properties[2] LYS	Properties[2] TYS	Exfoliation Visual Ratings[3] T/10	Exfoliation Visual Ratings[3] T/2
MA65 Alloy: Al-6.5 Zn-2.3 Mg-1.5 Cu					
404877-J2B	15.6	74.6	71.1	P	P
404879-K2B	48.5	77.8	70.9	P	P
MA66 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu					
404880-J3B	16.5	83.2	78.4	P	P
404882-N4B	49.3	86.8	79.4		
MA67 Alloy: Al-8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co					
404883-K5B	14.7	88.2	82.0	P	P

Notes:
1. Average Particle Diameter.
2. All sheet SHT @ 920 F, CWQ, stretched 1.8%, aged 5 days @ room temperature + 24 hours @ 250 F.
3. Ratings Code: N - no appreciable attack, surface may be etched.
   P - pitting: discrete pitting or pit-blistering common in exfoliation resistant commercially produced materials in this test.
   E - exfoliation: visible lifting of surface.

Table 90

PROPERTY GOALS OF TARGET B COMPARED TO MA66 ALLOY EXTRUSIONS

	Target	MA66 Alloy: 8.0 Zn-2.5 Mg-1.0 Cu
Y.S. - ksi	85	84.2
K_{Ic} - ksi$\sqrt{in.}$	26	28[1]
SCC - sustained stress - ksi	25	25
Fatigue Limit[2] - ksi k_t=3, R=0.0	14	18.5[3]
Exfoliation	Immune	Resistant
Elongation - %	11	11.2

Notes: 1. Approximate based on NTS/YS to K_{Ic} correlation.

2. Axial stress.

3. In test, intact at 8.77 x 10^6 cycles.

WSC:km
8-3-72

Table 91

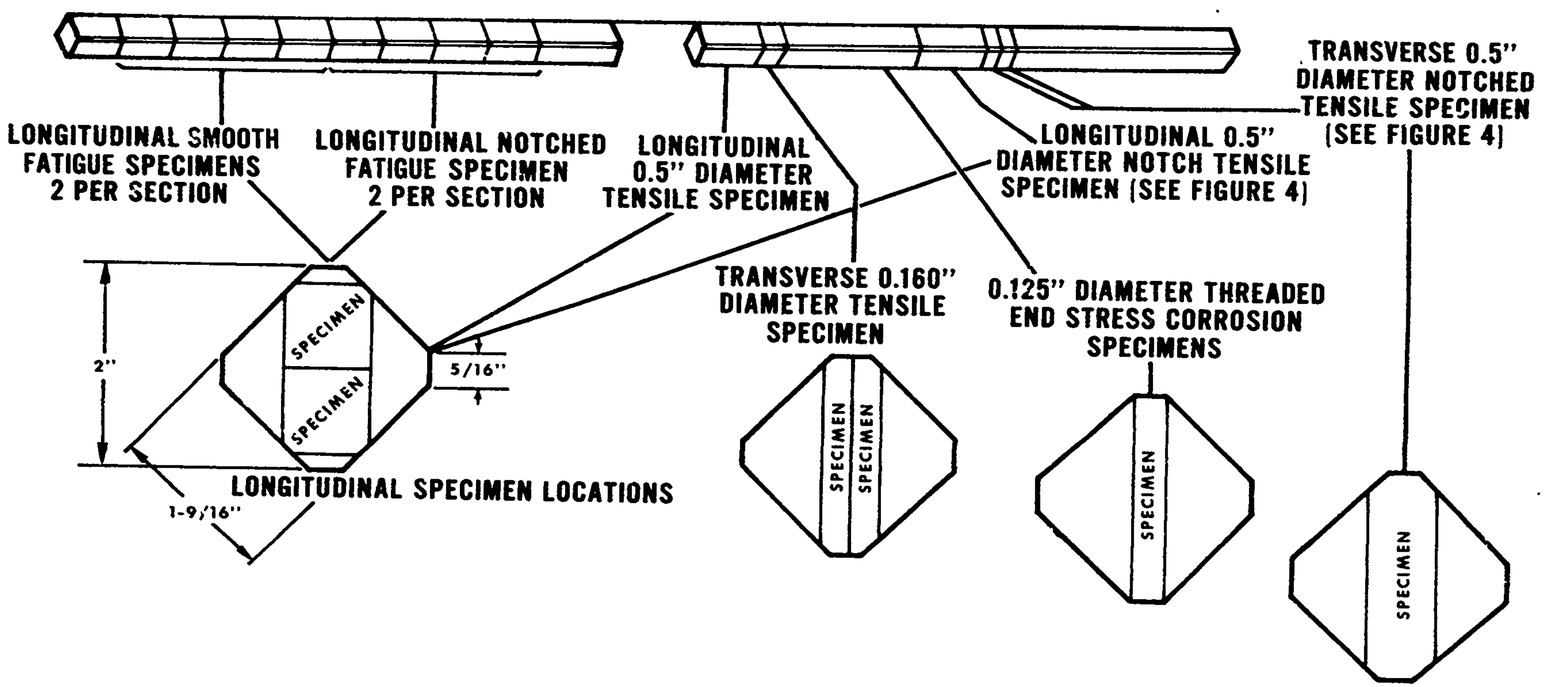
PROPERTY GOALS OF TARGET A COMPARED TO MA67 AND MA66 ALLOY EXTRUSIONS

	Target	MA67 Alloy 8.0 Zn-2.5 Mg-1.0 Cu-1.6 Co	MA66 Alloy: 8.0 Zn-2.5 Mg-1.0 Cu
Y.S. - ksi	95	95.9	94.3
K_{Ic} - ksi$\sqrt{in.}$	26	17[1]	26[1]
SCC - sustained stress - ksi	25	25	<25
Fatigue Limit[2] - ksi k_t=3, R=0.0	14	20	20
Exfoliation	Resistant	Resistant	Resistant
Elongation - %	11	7.8	8.0

Notes: 1. Approximate K_{Ic} based on NTS/YS to K_{Ic} correlation.

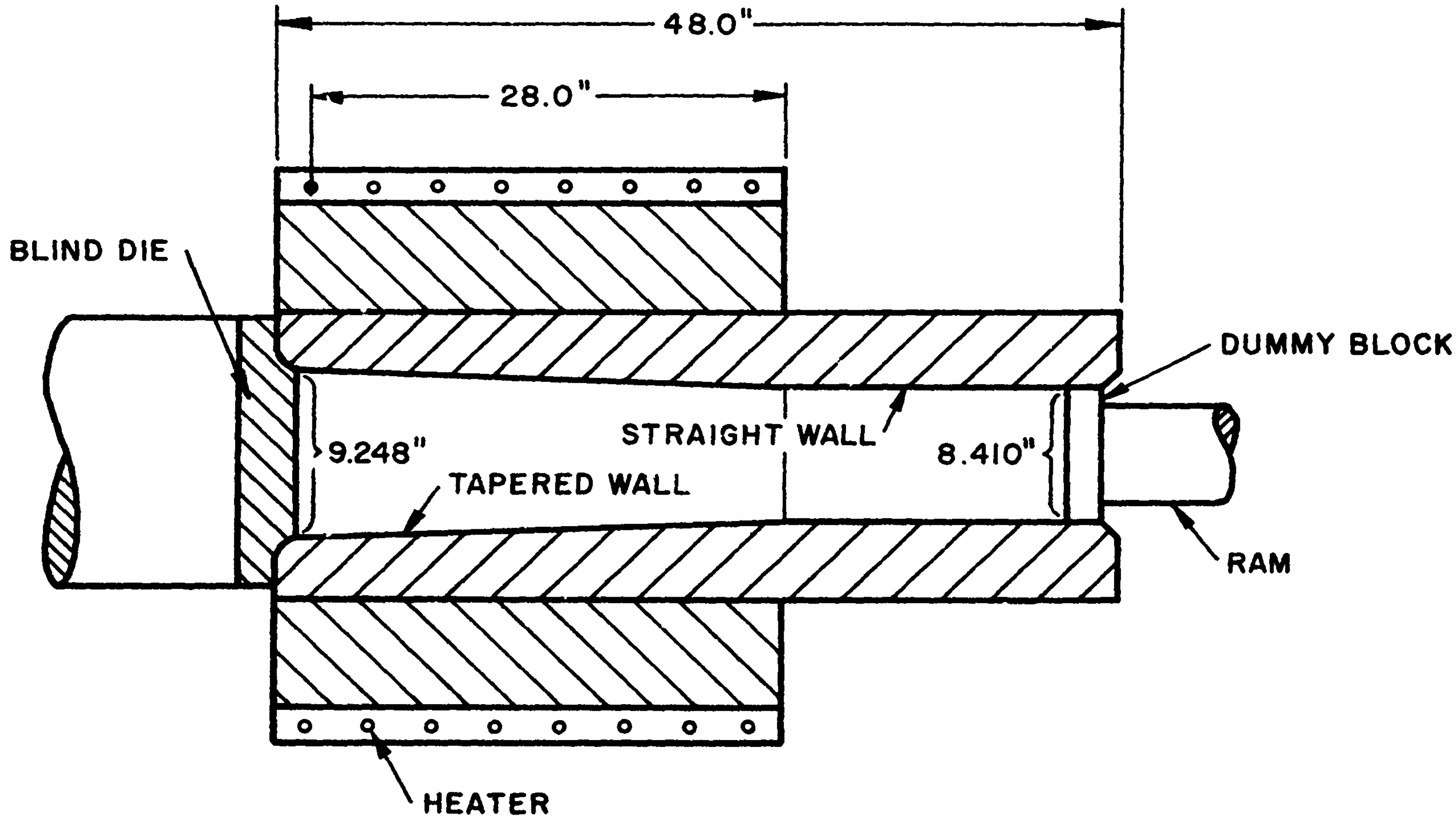
2. Axial stress.

WSC:km
8-3-72

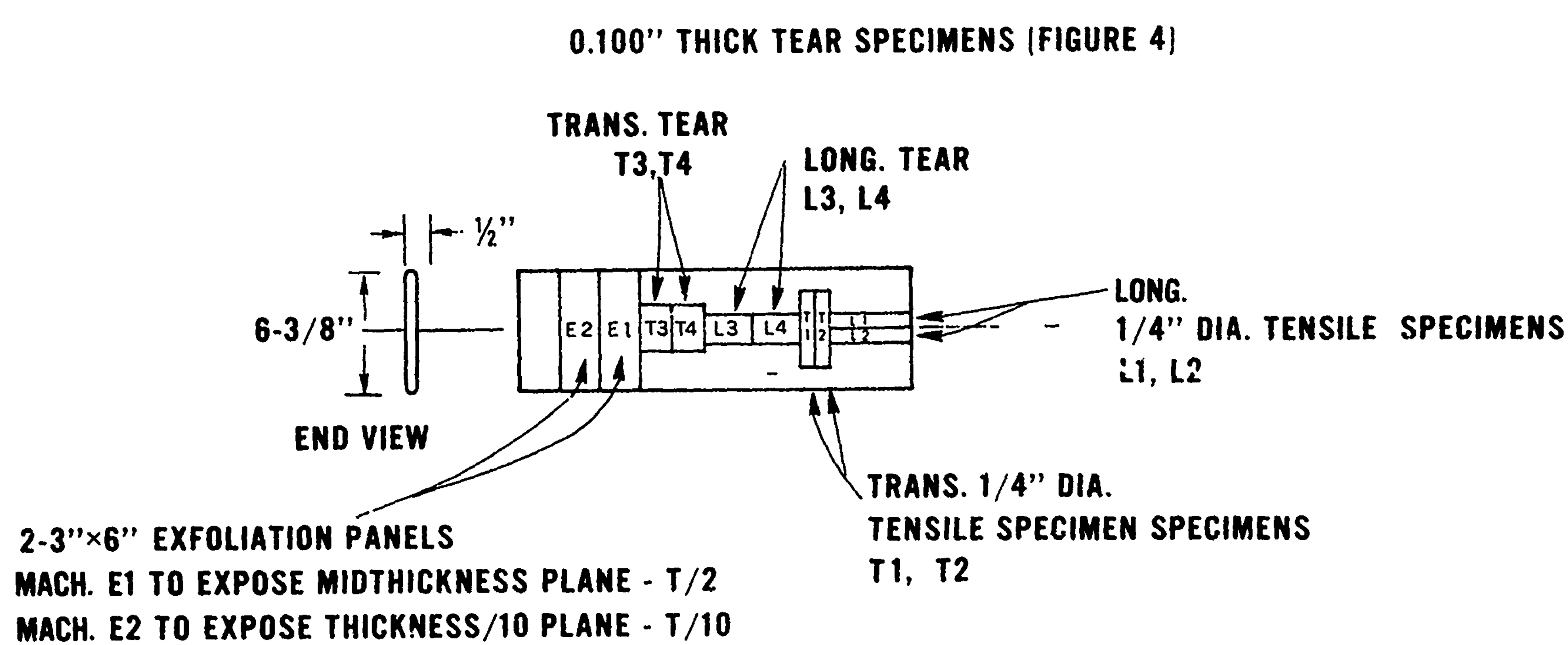


SPECIMEN LAYOUT FOR OCTAGONAL EXTRUSION

FIGURE 1

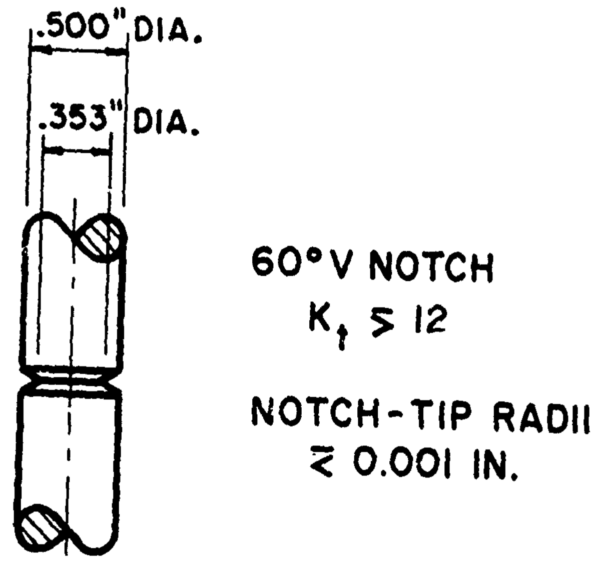


SCHEMATIC OF 8.4 IN. DIA. HOT COMPACTING CYLINDER
FIG. 2

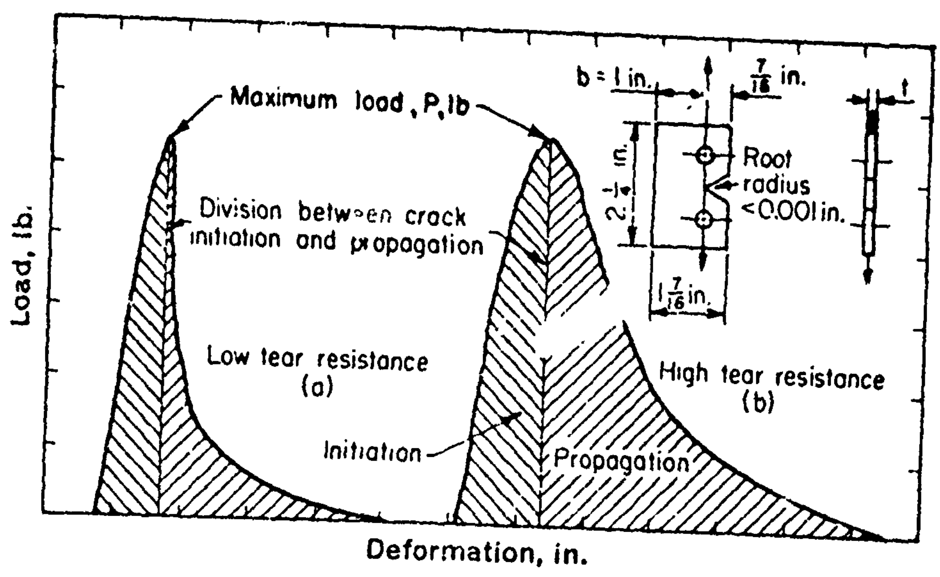


SPECIMEN LAYOUT FOR ½"×6-3/8" EXTRUDED BAR.

FIGURE 3

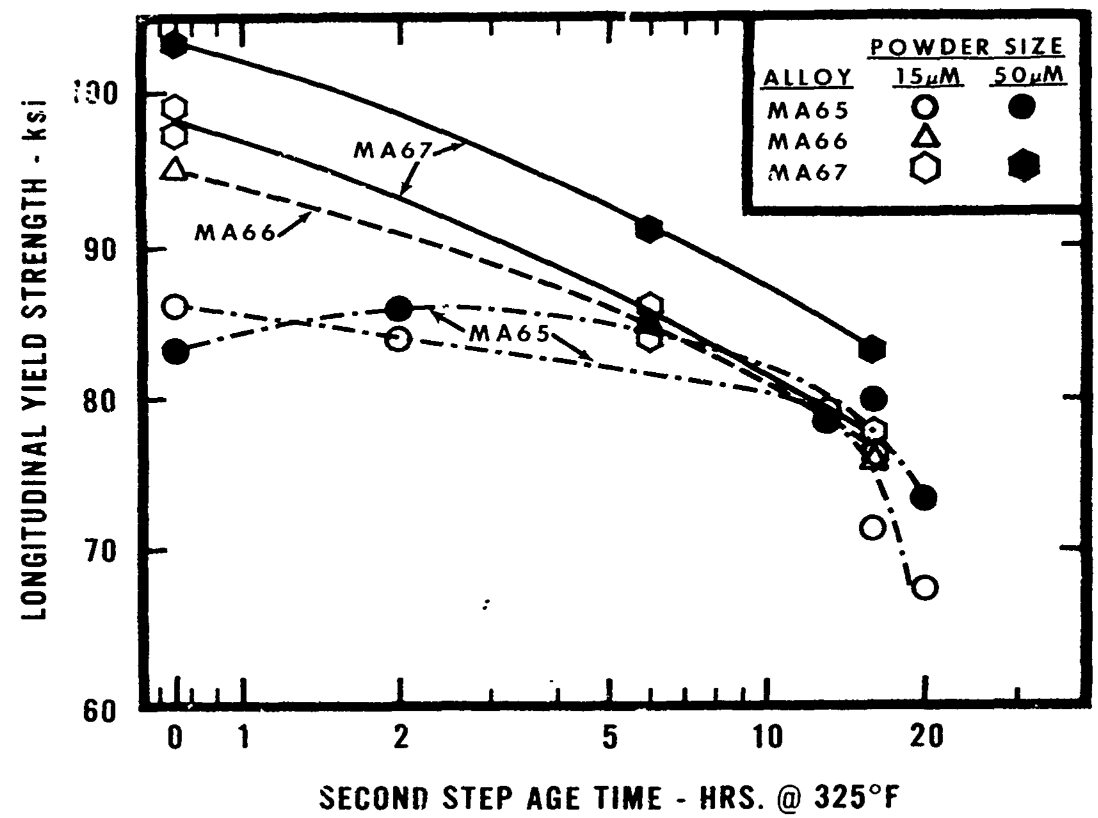


4a. NOTCHED TENSILE-TEST SPECIMEN



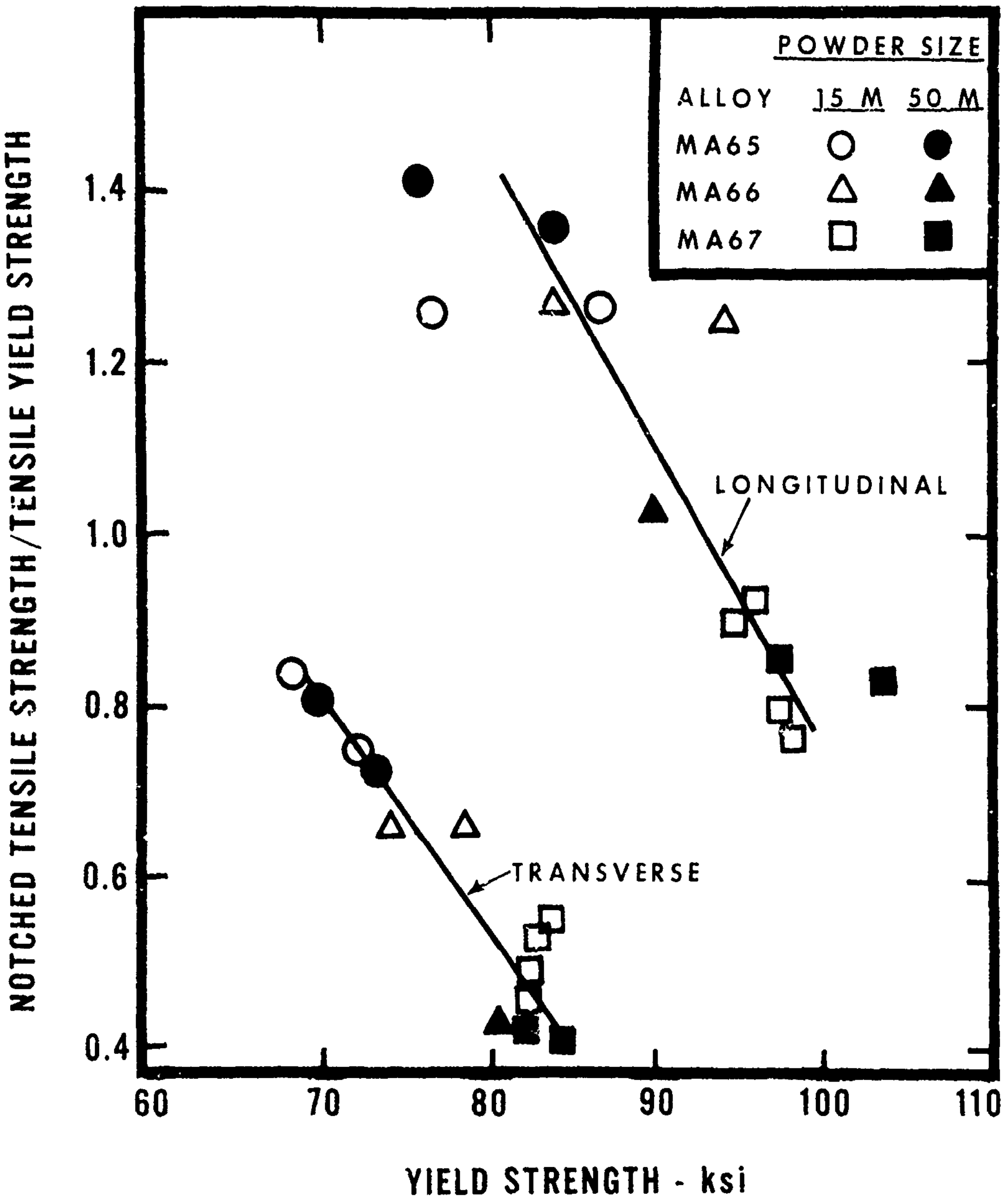
4b. TEAR-TEST SPECIMEN AND REPRESENTATION OF LOAD-DEFORMATION CURVES.

FIG. 4



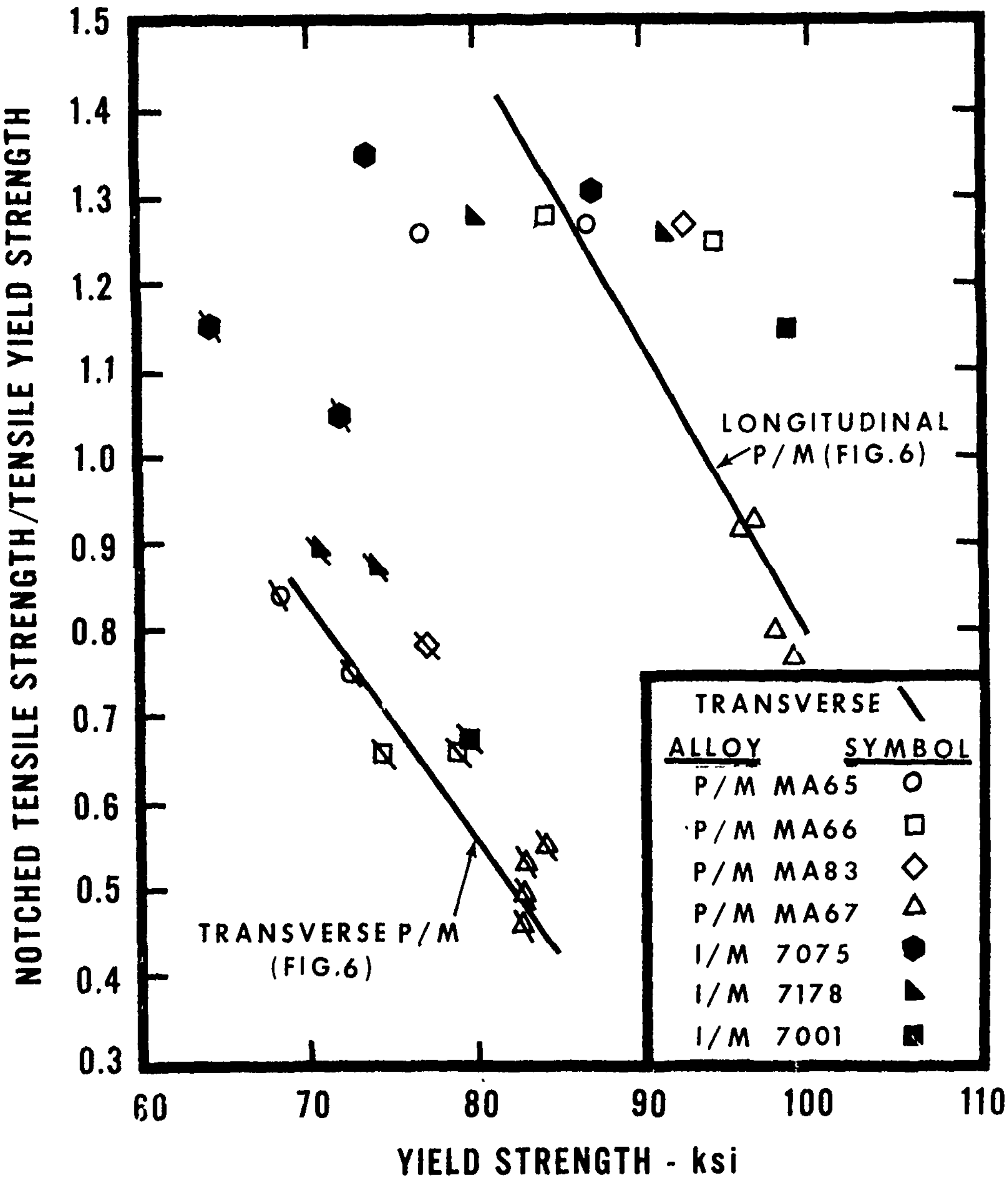
EFFECT OF SECOND STEP AGE TIME ON LONGITUDINAL YIELD STRENGTH OF P/M OCTAGONAL EXTRUSIONS

FIGURE 5



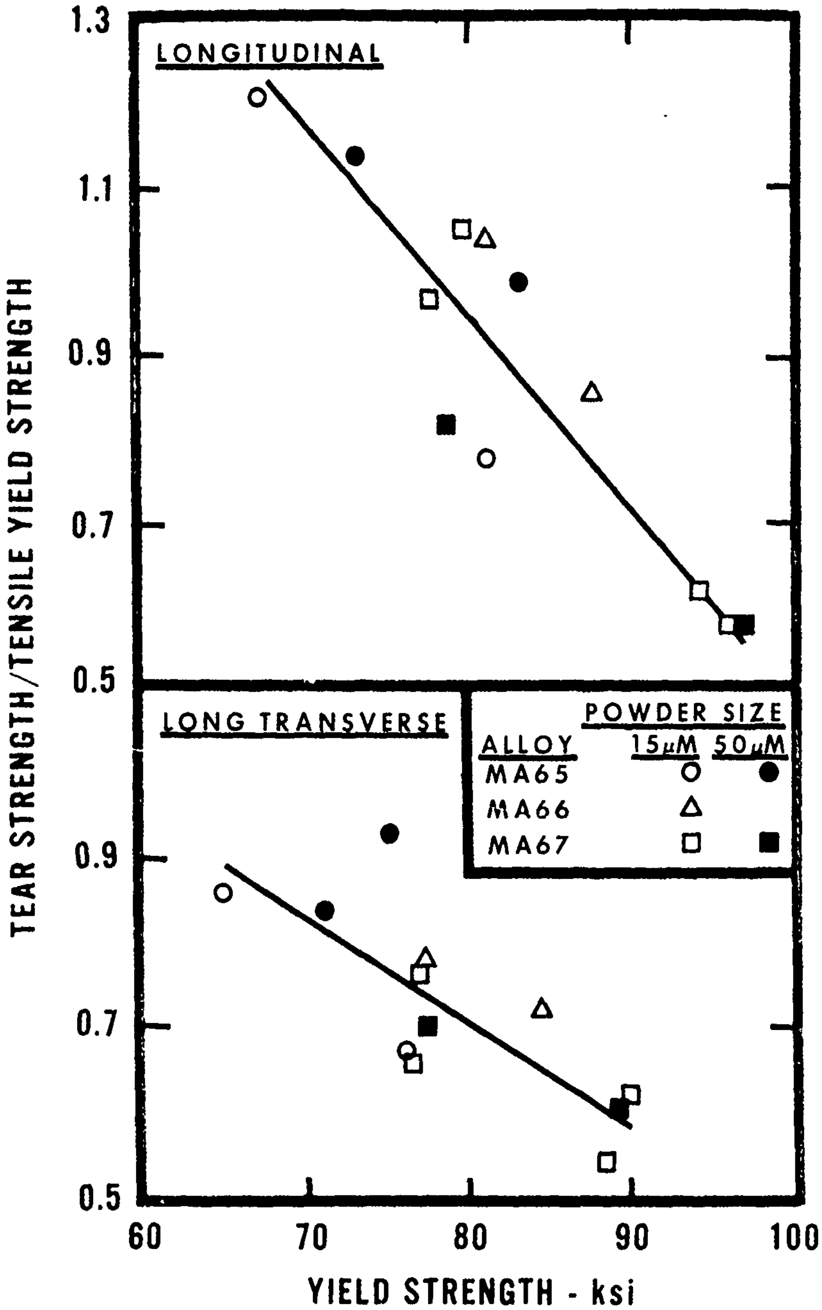
EFFECT OF POWDER SIZE ON THE YIELD STRENGTH TO NTS/YS RELATIONSHIP FOR OCTAGONAL EXTRUDED BAR.

FIGURE 6



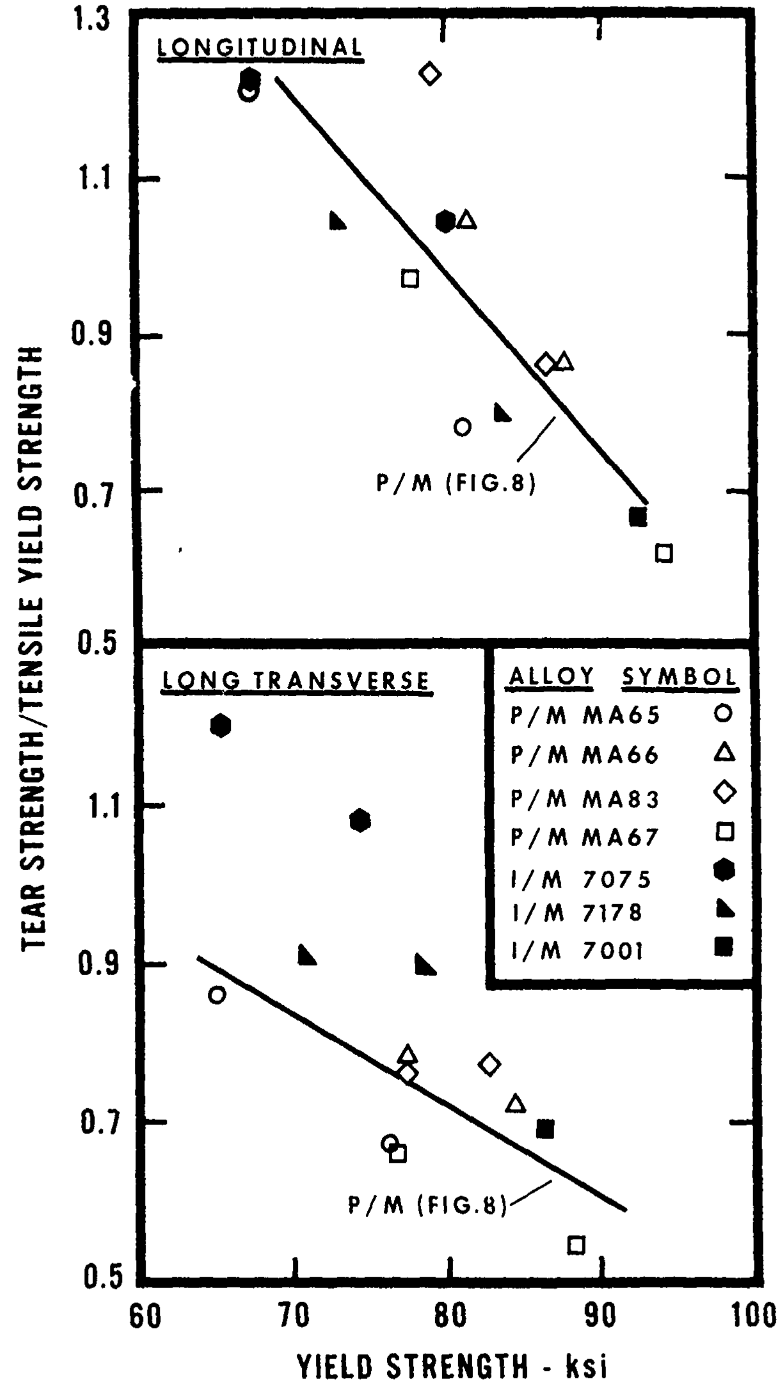
COMPARISON OF FRACTURE TOUGHNESS OF FINE POWDER P/M ALLOYS TO INGOT (I/M) ALLOYS IN OCTAGONAL EXTRUDED BAR.

FIGURE 7



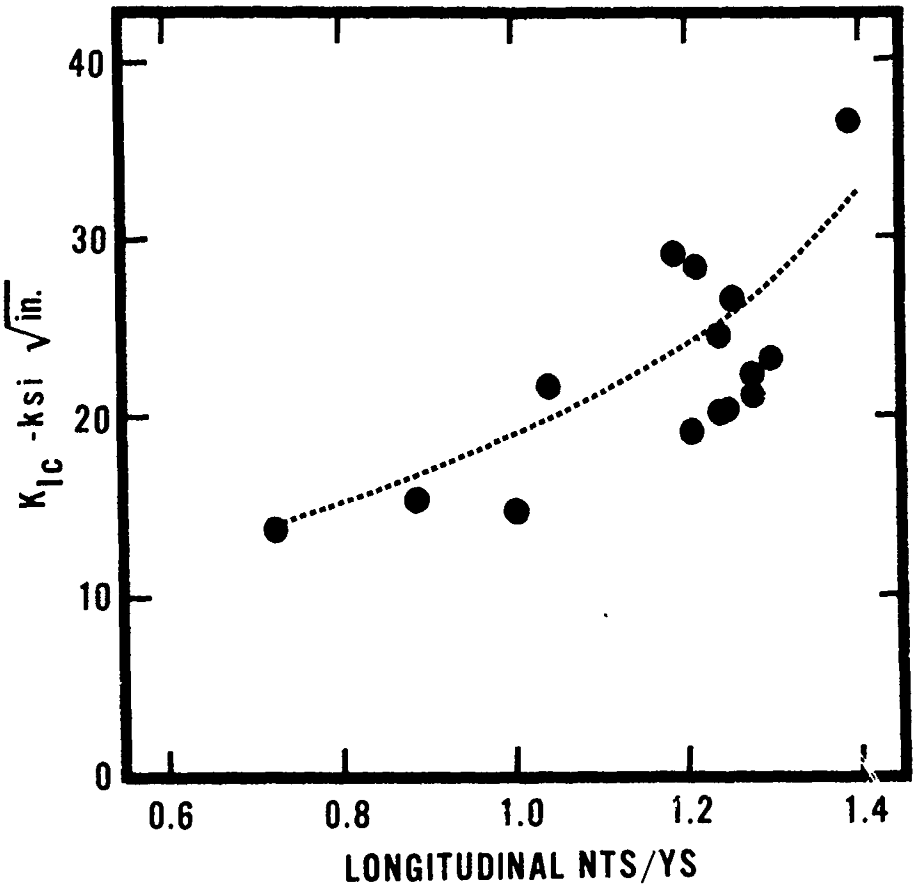
EFFECT OF POWDER SIZE ON THE YIELD STRENGTH TO TR.S./Y.S. RELATIONSHIP FOR P/M ½"×6" EXTRUDED BAR

FIGURE 8



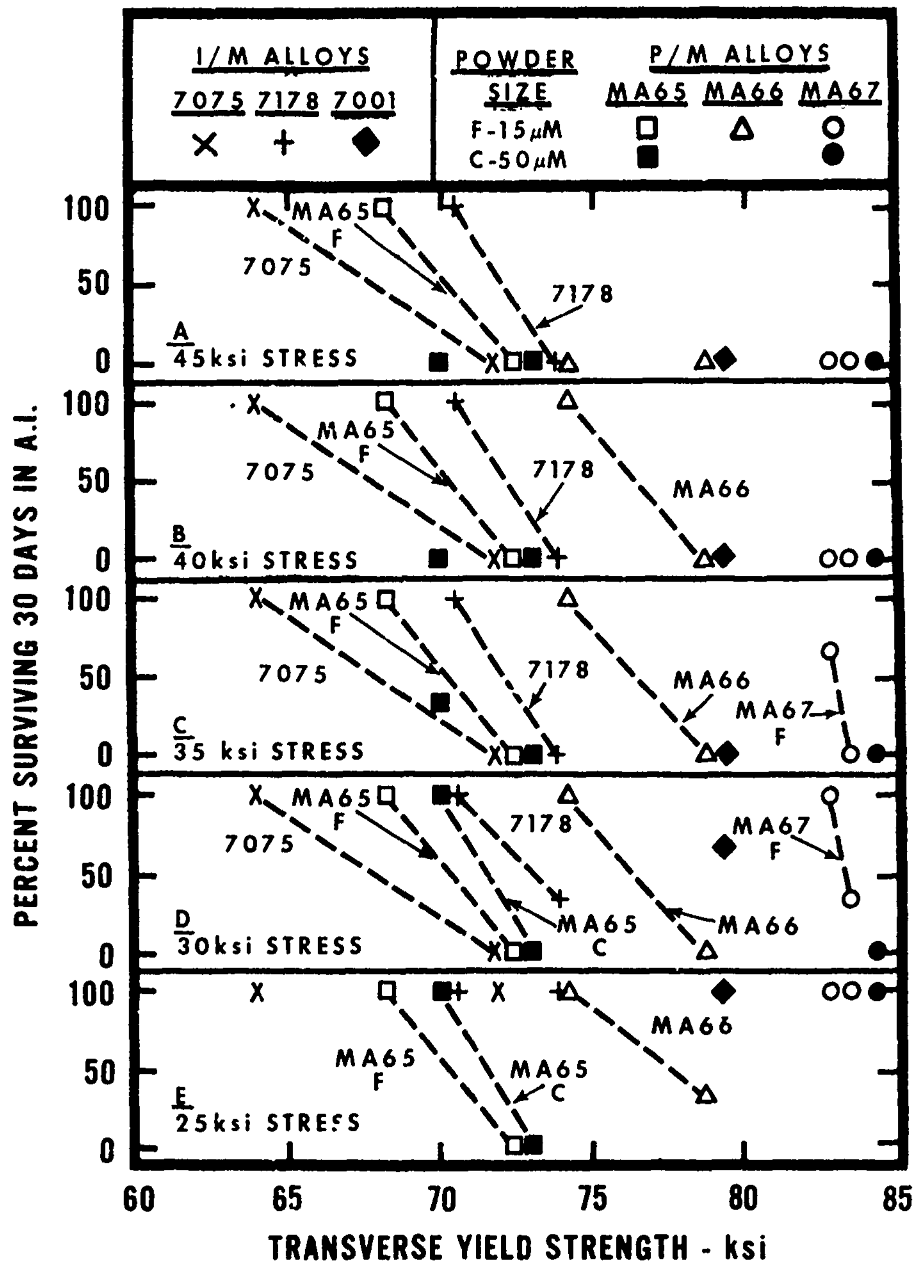
COMPARISON OF TOUGHNESS OF FINE POWDER P/M ALLOYS TO INGOT (I/M) SAMPLES FROM 1/2"× 6-3/8" EXTRUDED BAR

FIGURE 9



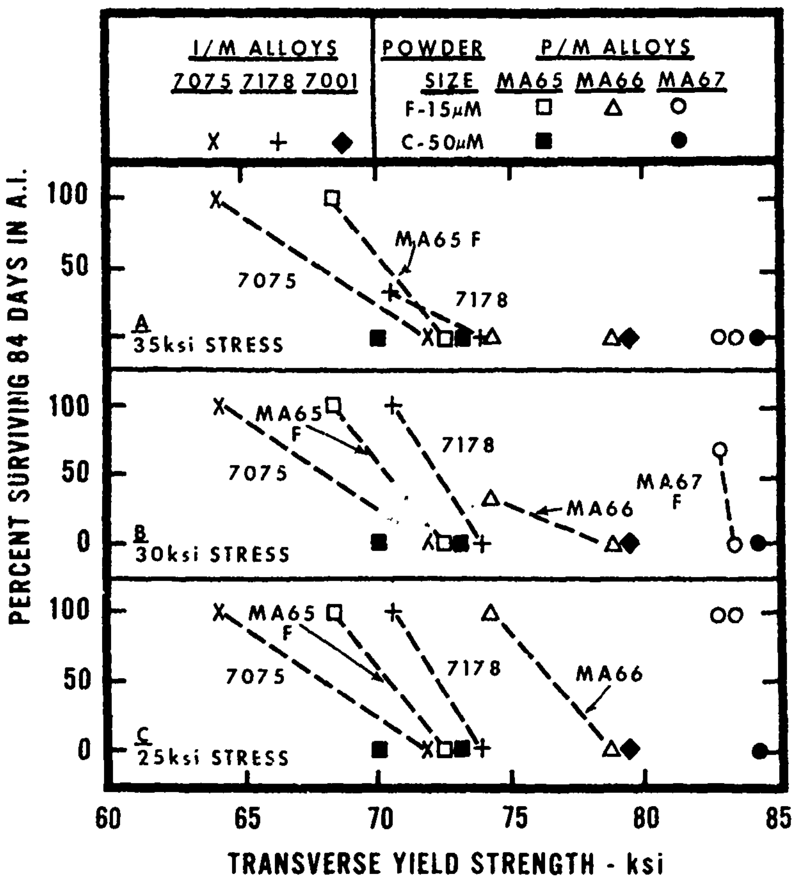
CORRELATION BETWEEN K_{Ic} VS LONGITUDINAL NTS/YS
P/M ALLOY EXTRUSIONS (FROM REF. 5)

FIGURE 10



EFFECT OF TRANSVERSE YIELD STRENGTH AND APPLIED STRESS ON PERCENT SURVIVAL FOR 30 DAYS EXPOSURE IN THE ALTERNATE IMMERSION STRESS CORROSION TEST. TRANSVERSE TENSILE BARS FROM OCTAGONAL EXTRUDED BAR.

FIGURE 11

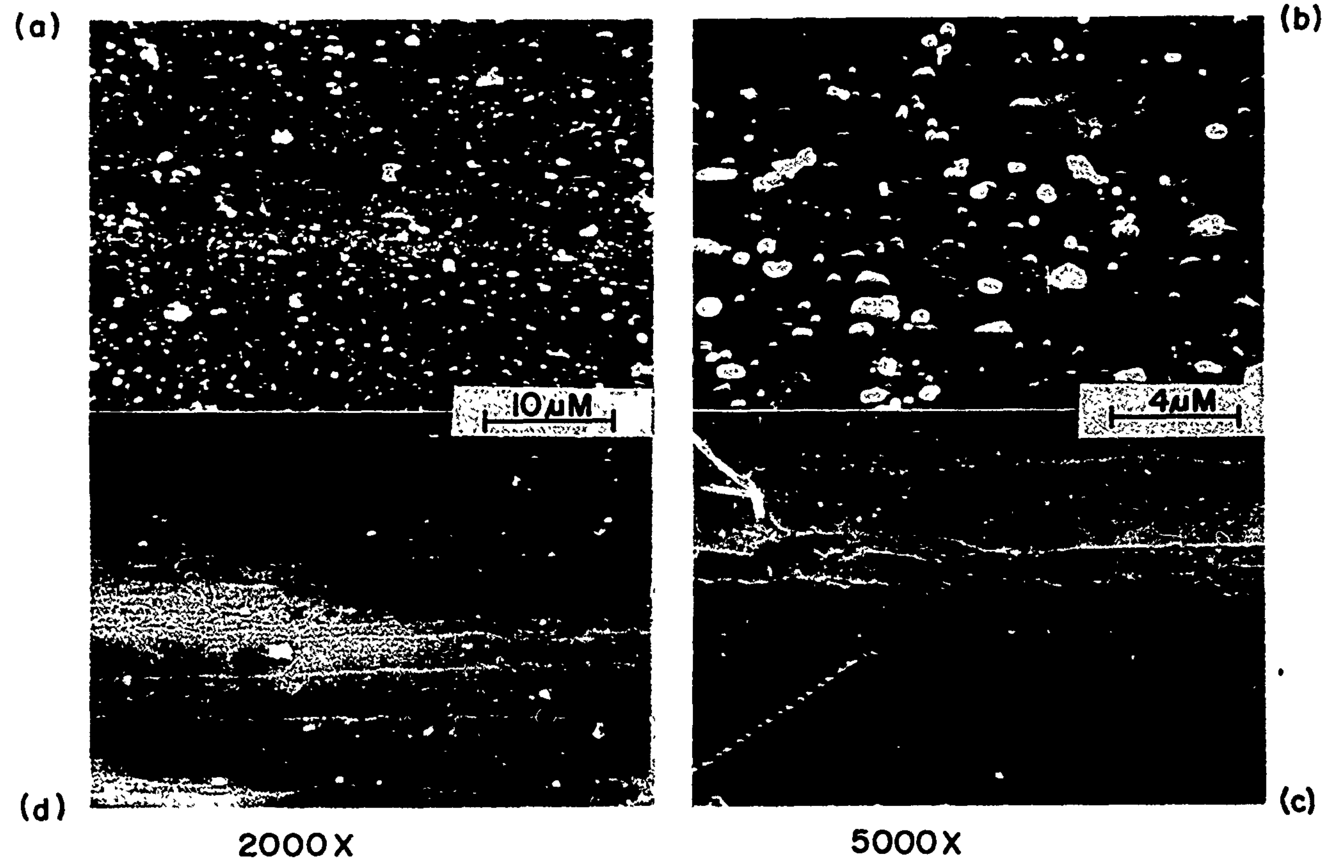


EFFECT OF TRANSVERSE YIELD STRENGTH AND APPLIED STRESS ON PERCENT SURVIVAL FOR 84 DAYS EXPOSURE IN THE ALTERNATE IMMERSION STRESS CORROSION TEST. TRANSVERSE TENSILE BARS FROM OCTAGONAL EXTRUDED BAR.

FIGURE 12

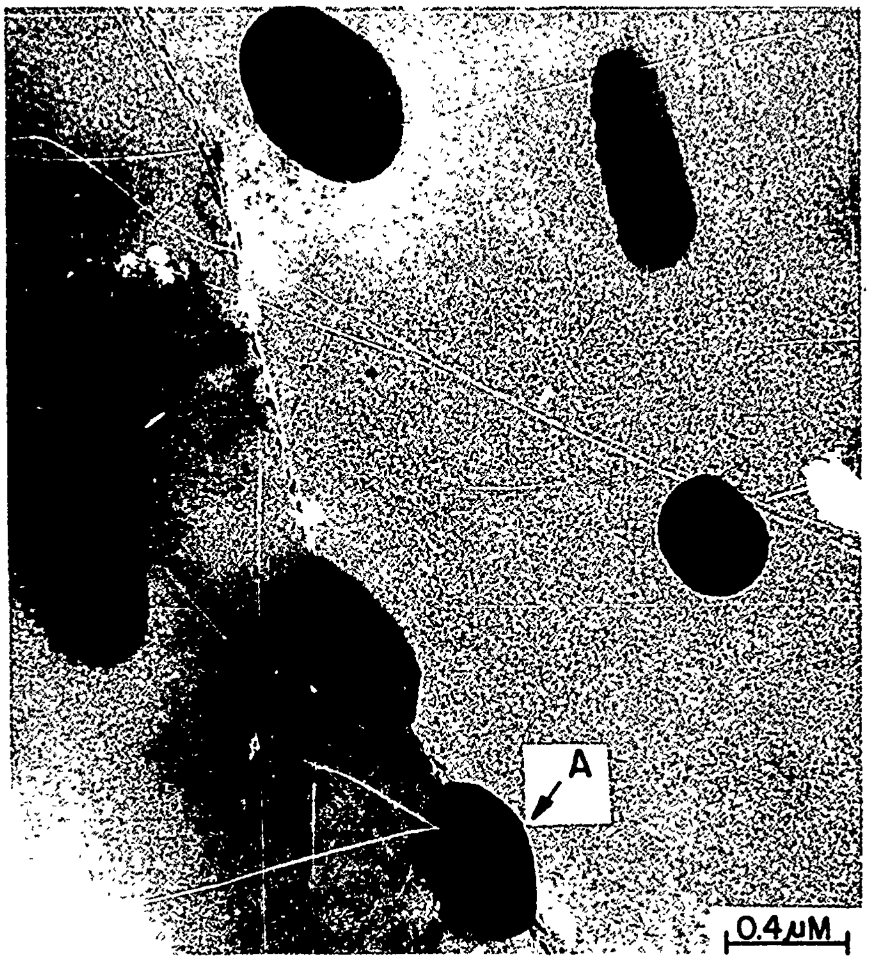
MA67 ALLOY EXTRUSION: Al-8Zn-2.5Mg-1Cu-1.6 Co

MA66 ALLOY EXTRUSION: Al-8Zn-2.5Mg-1Cu



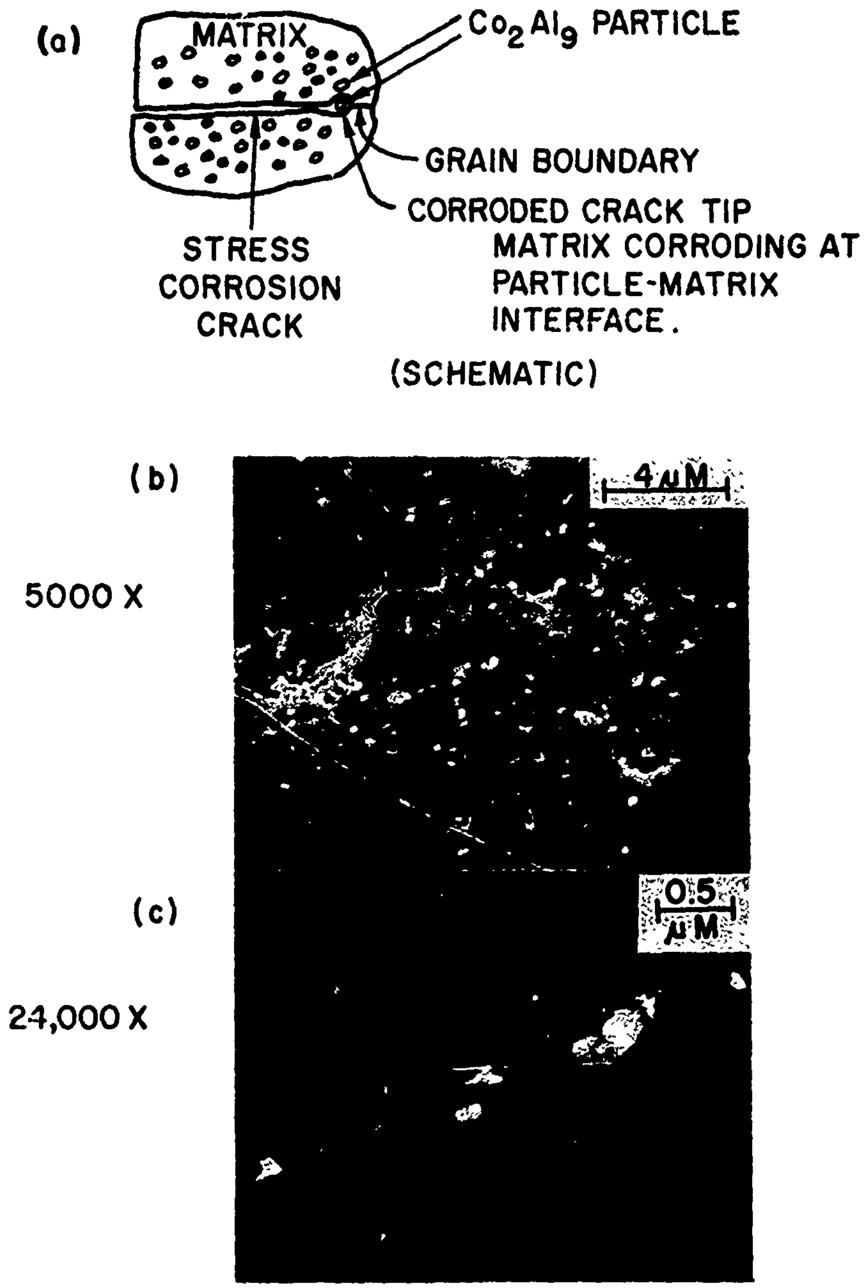
METALLURGICAL STRUCTURE OF LONGITUDINAL SECTIONS FROM P/M MA66 AND MA67 EXTRUSIONS. SEM, BROMINE ETCH. ROUND, WHITE CONSTITUENT IN (a) AND (b) ARE $Co_2 Al_9$ PARTICLES.

FIG. 13



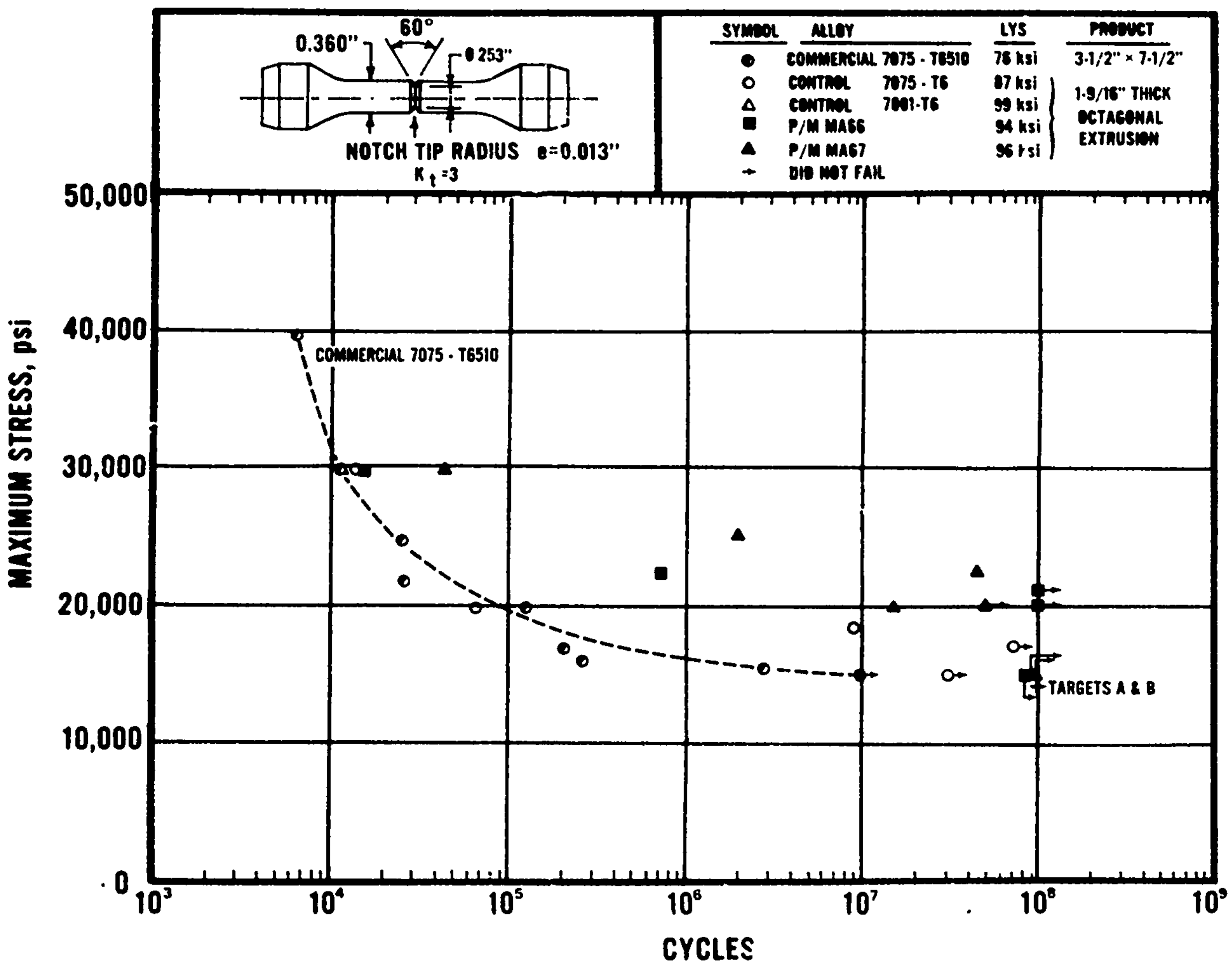
ELECTRON MICROSTRUCTURE OF P/M MA67 ALLOY (Al-8Zn-2.5Mg-1Cu-1.6Co). NOTE Co_2Al_9 PARTICLES (A) SUBSTANTIALLY LARGER THAN PRECIPITATE FREE ZONE AND LARGER THAN THE GRAIN BOUNDARY PRECIPITATE. 50,000 X, TEM.

FIG. 14



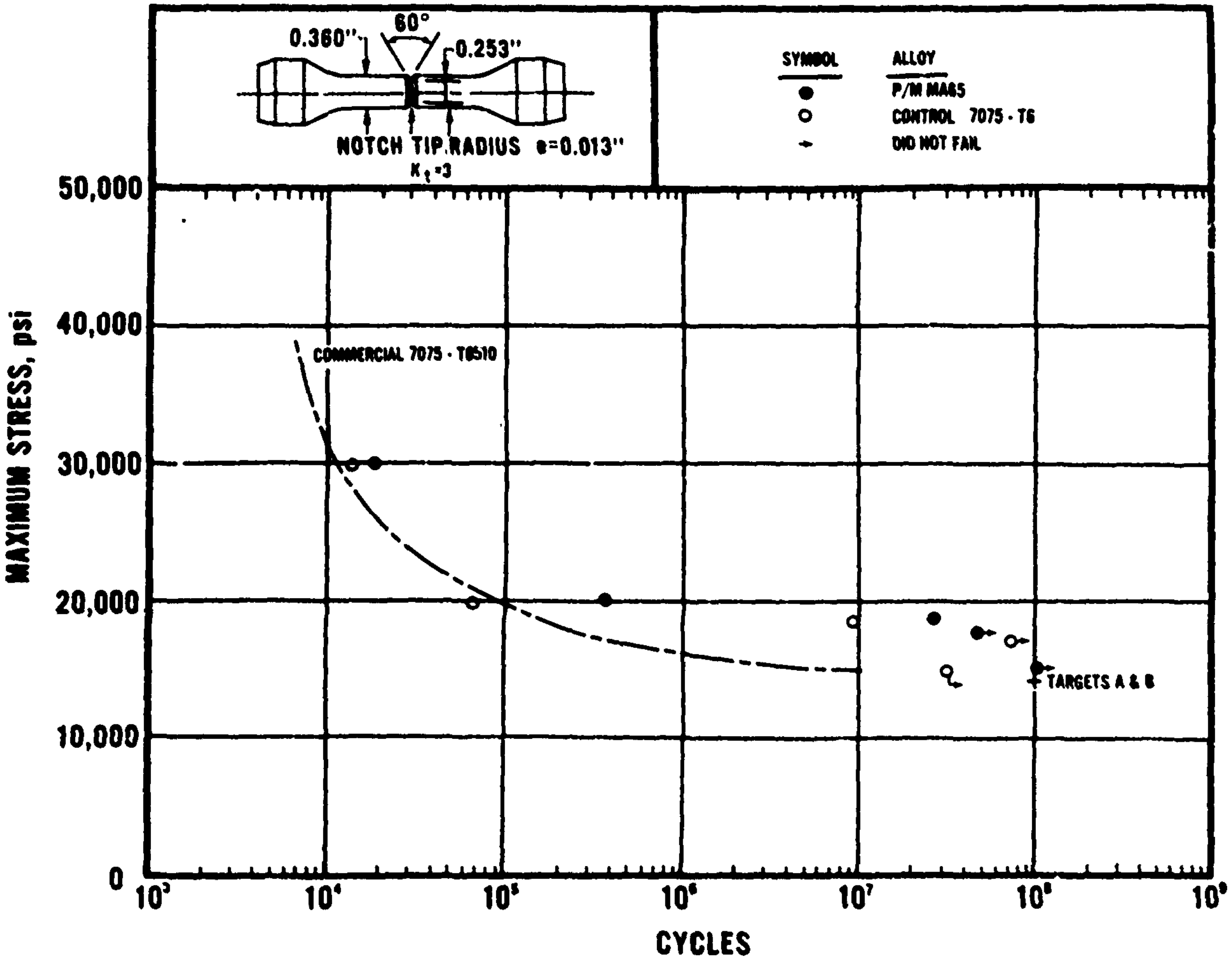
STRESS CORROSION CRACK BLUNTING BY Co_2Al_9 PARTICLES THAT OCCUR AT GRAIN BOUNDARIES. MICROSTRUCTURES FROM A TRANSVERSE TENSILE BAR FROM A Al-9.7 Zn-4.1 Mg-0.8 Cu-1.4 Co ALLOY P/M EXTRUSION. STRESSED AT 25 KSI, EXPOSED 1595 DAYS IN NEW KENSINGTON ATMOSPHERE.

FIG. 15



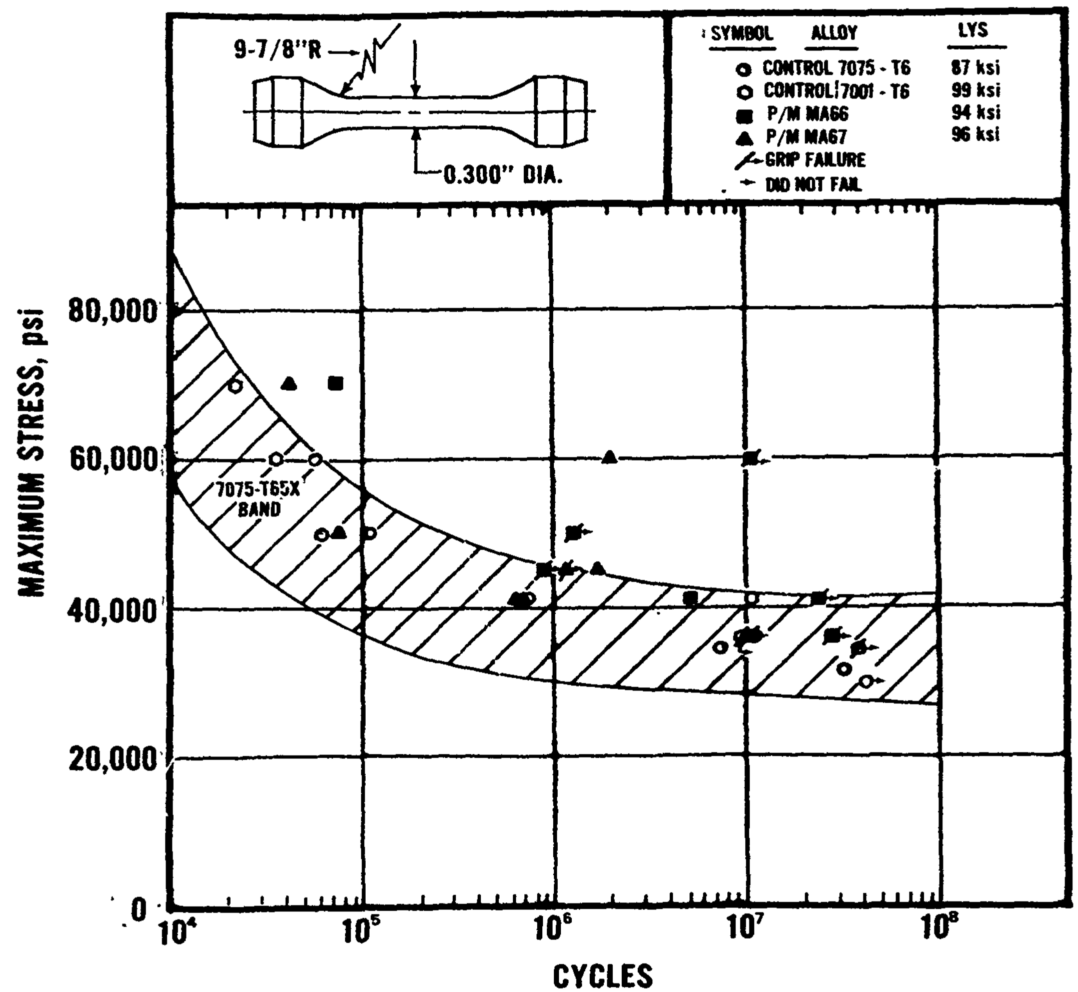
NOTCHED AXIAL-STRESS FATIGUE PERFORMANCE OF ALUMINUM ALLOY OCTAGONAL EXTRUSIONS COMPARED TO 7075-T6510 EXTRUDED BAR (REF. 9). STRESS RATIO = 0.0

FIGURE 16



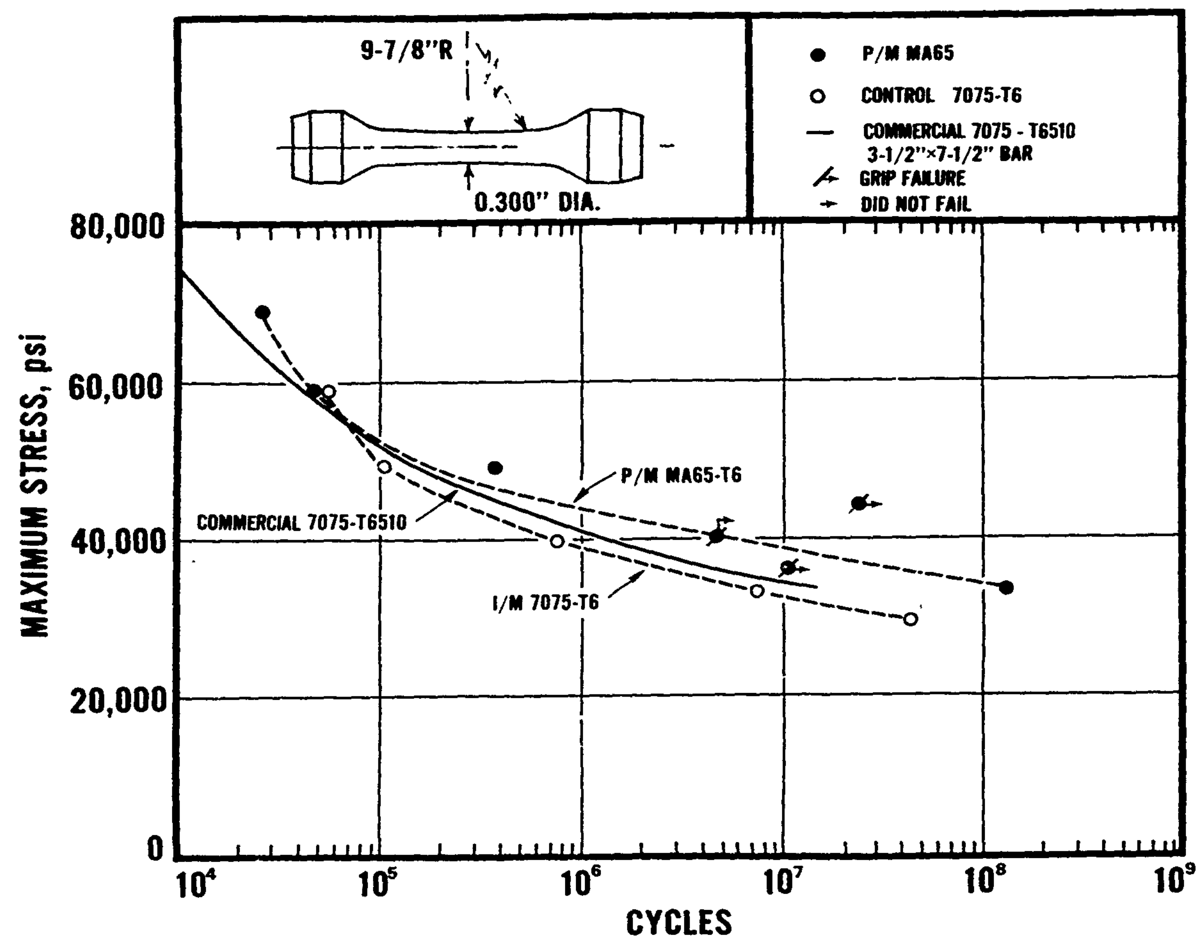
EFFECT OF MATERIAL ON NOTCHED FATIGUE PERFORMANCE OF EXTRUSIONS AGED TO 87ksi LONGITUDINAL YIELD STRENGTH. STRESS RATIO=0.0 AXIAL STRESS

FIGURE 17



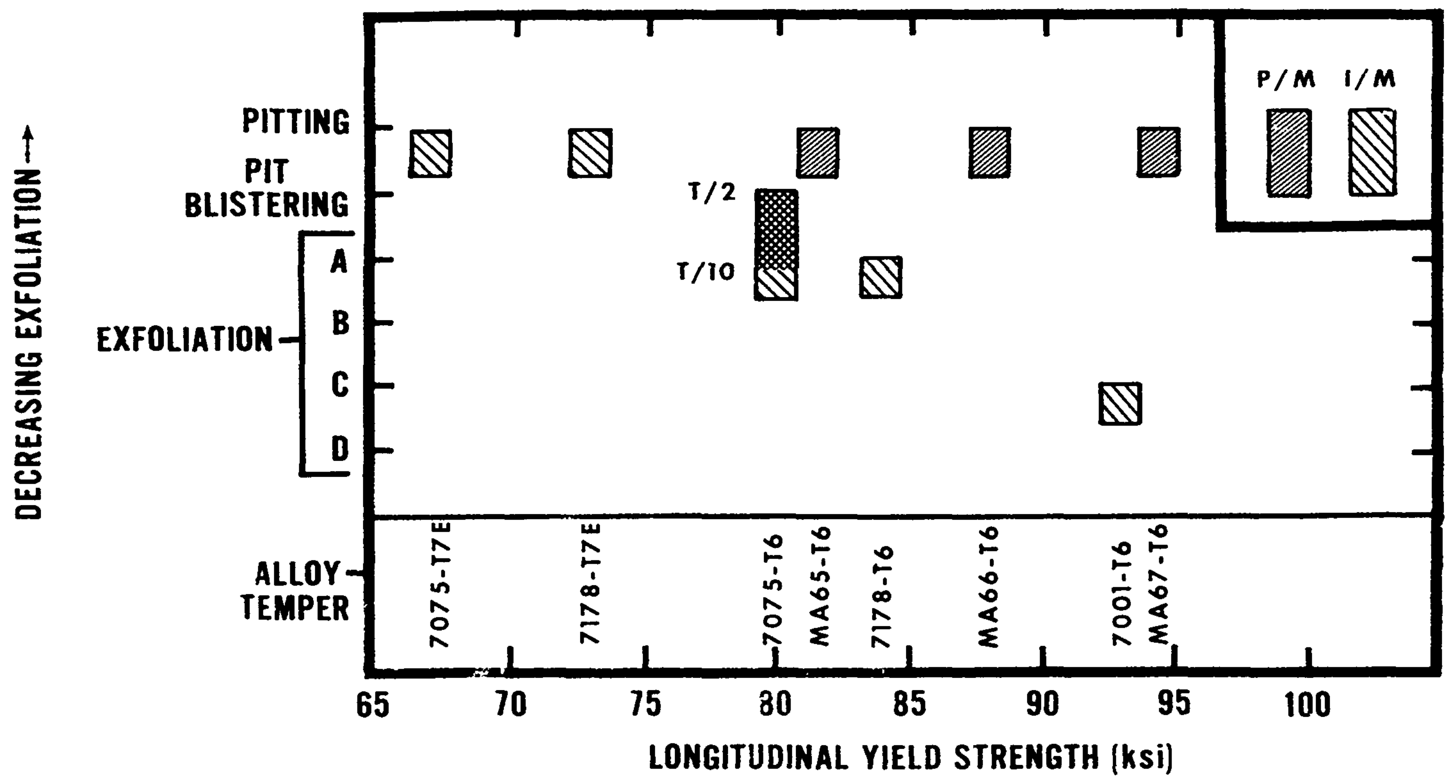
SMOOTH AXIAL-STRESS FATIGUE PERFORMANCE OF ALUMINUM ALLOY OCTAGONAL EXTRUSIONS COMPARED TO 7075-T65X PRODUCTS. STRESS RATIO = 0.0

FIGURE 18



EFFECT OF MATERIAL ON FATIGUE PERFORMANCE OF EXTRUSIONS AGED TO 87 ksi LONGITUDINAL YIELD STRENGTH. STRESS RATIO = 0.0

FIGURE 19



STRENGTH AND EXFOLIATION RESISTANCE OF P/M AND I/M EXTRUSIONS. MIDPLANE AND 10% OF THICKNESS PLANES OF 1/2"×6-3/8" EXTRUSION EXPOSED 48 HOURS IN "EXCO" IMMERSION TEST.

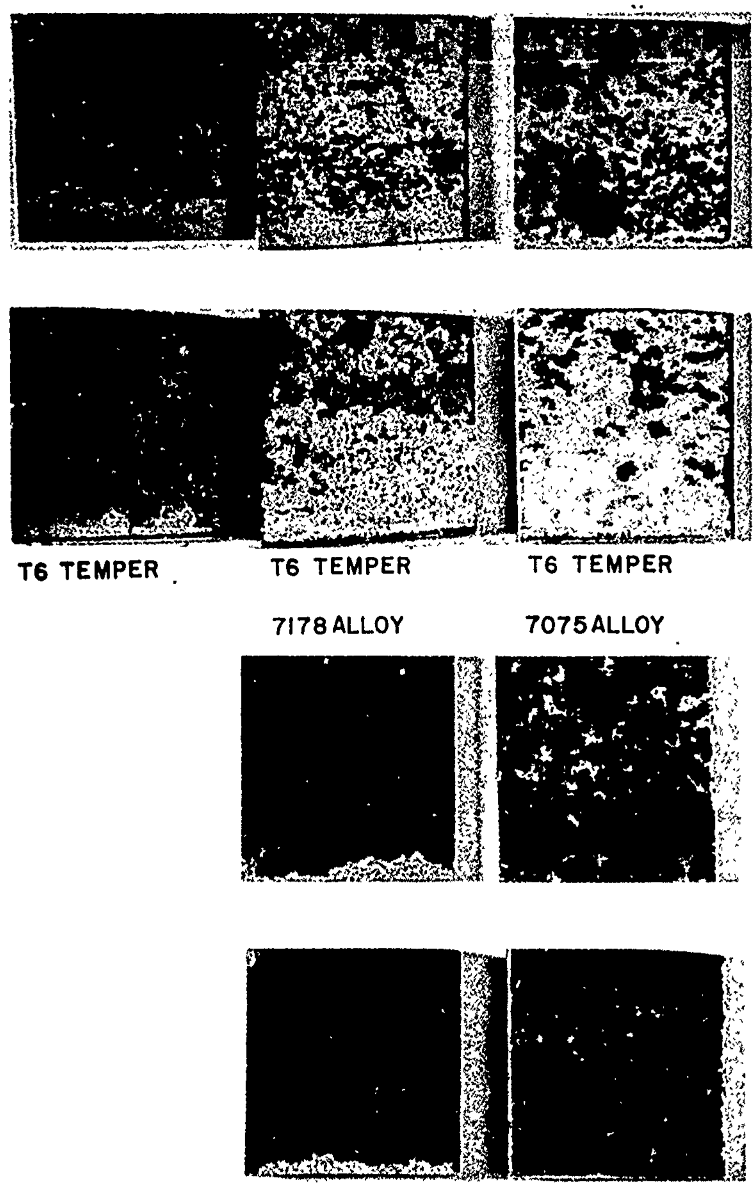
FIGURE 20

EXPOSED 48 HOURS IN EXCO IMMERSION TEST

7001 ALLOY | 7178 ALLOY | 7075 ALLOY

MID-PLANE

10% BELOW EXTRUDED SURFACE



T6 TEMPER | T6 TEMPER | T6 TEMPER

7178 ALLOY | 7075 ALLOY

MID-PLANE

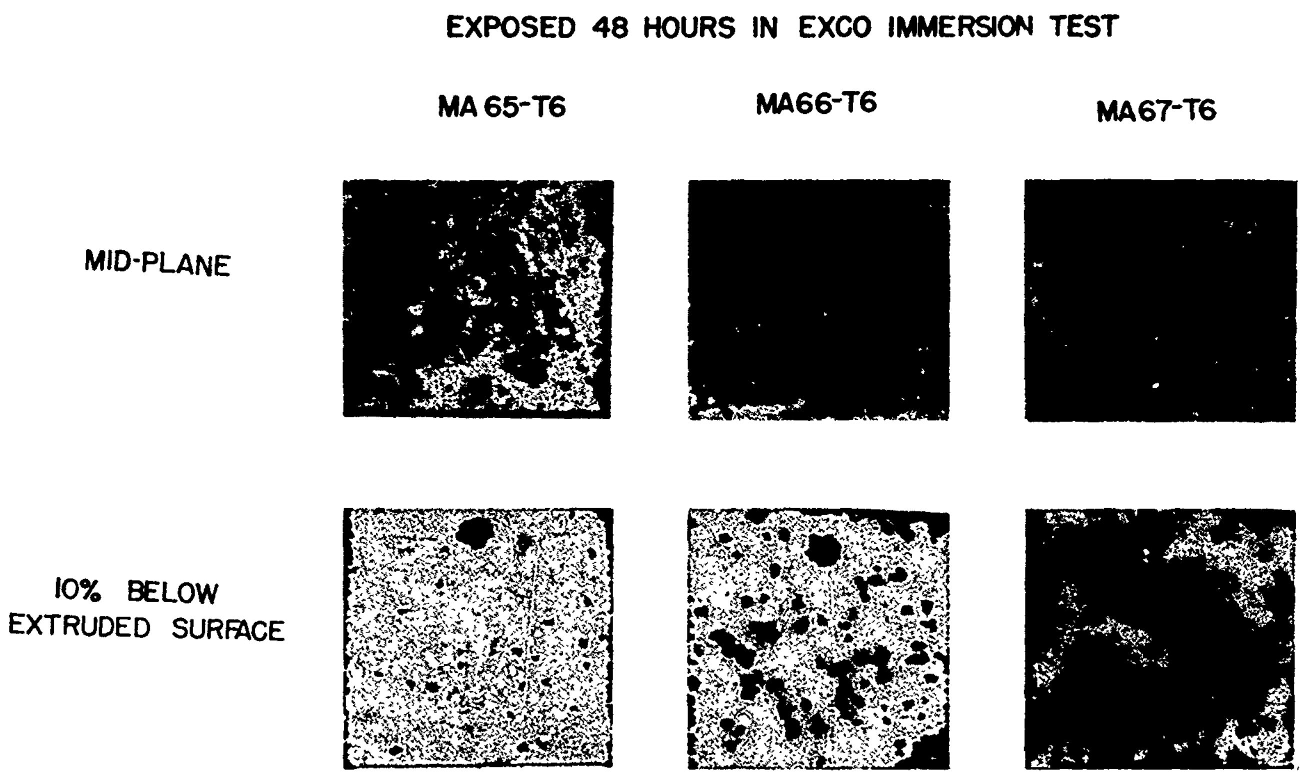
10% BELOW EXTRUDED SURFACE

T6+ 10 Hrs. AT 325°f | T6+ 24 Hrs. AT 325°f

ALCOA

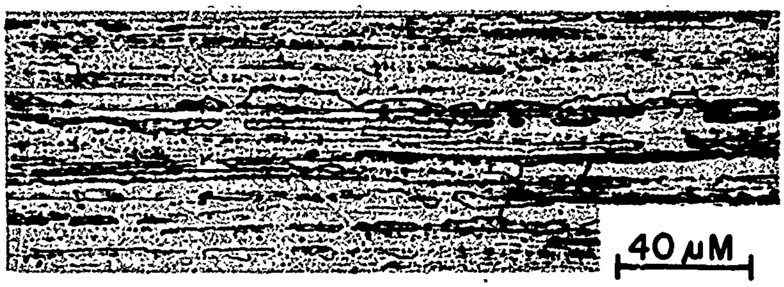
EXCO EXFOLIATION CORROSION PERFORMANCE OF CONTROL I/M 7075, 7178 AND 7001 1/2 X 6-3/8 IN. EXTRUSIONS. NOTE EXFOLIATION CORROSION PARTICULARLY EVIDENT IN 7001-T6 AND 7178-T6, AND SLIGHT IN 7075-T6.

FIG. 21

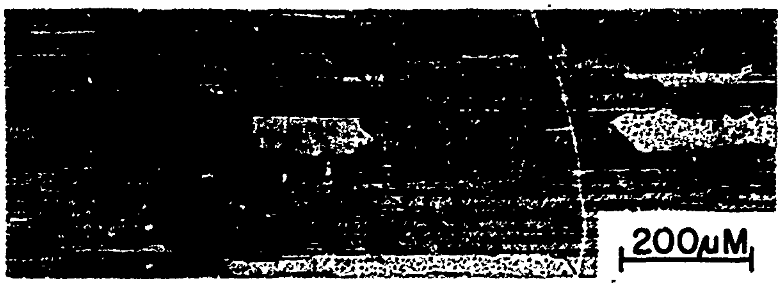


EXCO EXFOLIATION CORROSION PERFORMANCE OF P/M 1/2"X 6-3/8 EXTRUSIONS FROM 15μ POWDERS AT MAXIMUM STRENGTH. NOTE ABSENCE OF SURFACE LIFTING AND ONLY PITTING CORROSION ATTACK.

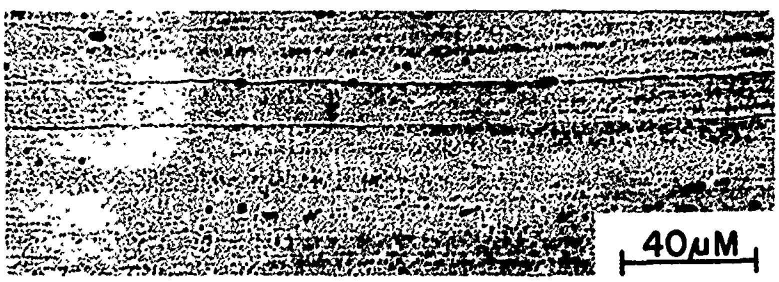
FIG. 22



a. MA65 ALLOY EXTRUSION FROM 15 µM POWDER
500X, KELLER'S ETCH.



b. MA65 ALLOY EXTRUSION FROM 50 µM POWDER
100X, KELLER'S ETCH.

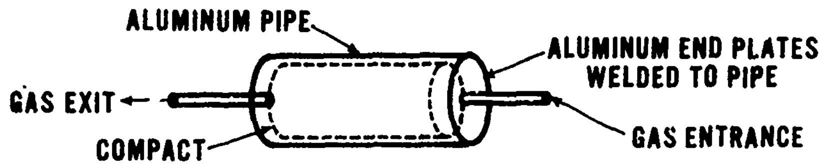


c. I/M 7075 ALLOY EXTRUSION.
500X, KELLER'S ETCH.

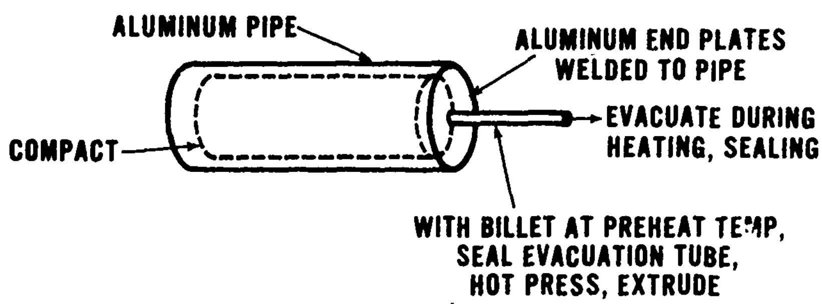
LONGITUDINAL STRUCTURE OF P/M MA65 AND I/M 7075 1/2 IN. X 6-3/8 IN. EXTRUDED BARS NEAR MID-THICKNESS.

FIG. 23

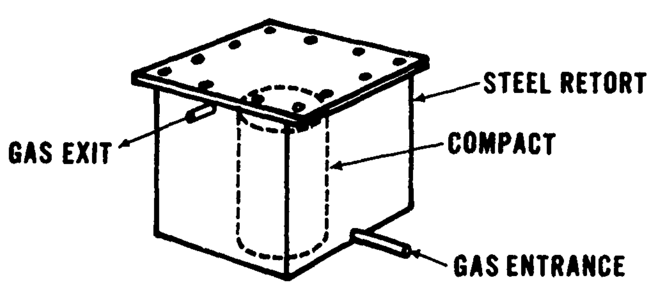
A.) "CANAR" OR "CANIT" PREHEAT METHODS
CAN PREHEAT WITH FLOWING ARGON OR NITROGEN



B.) "VAC" OR "AVAC" PREHEAT METHODS
VACUUM PREHEAT/HOT PRESS

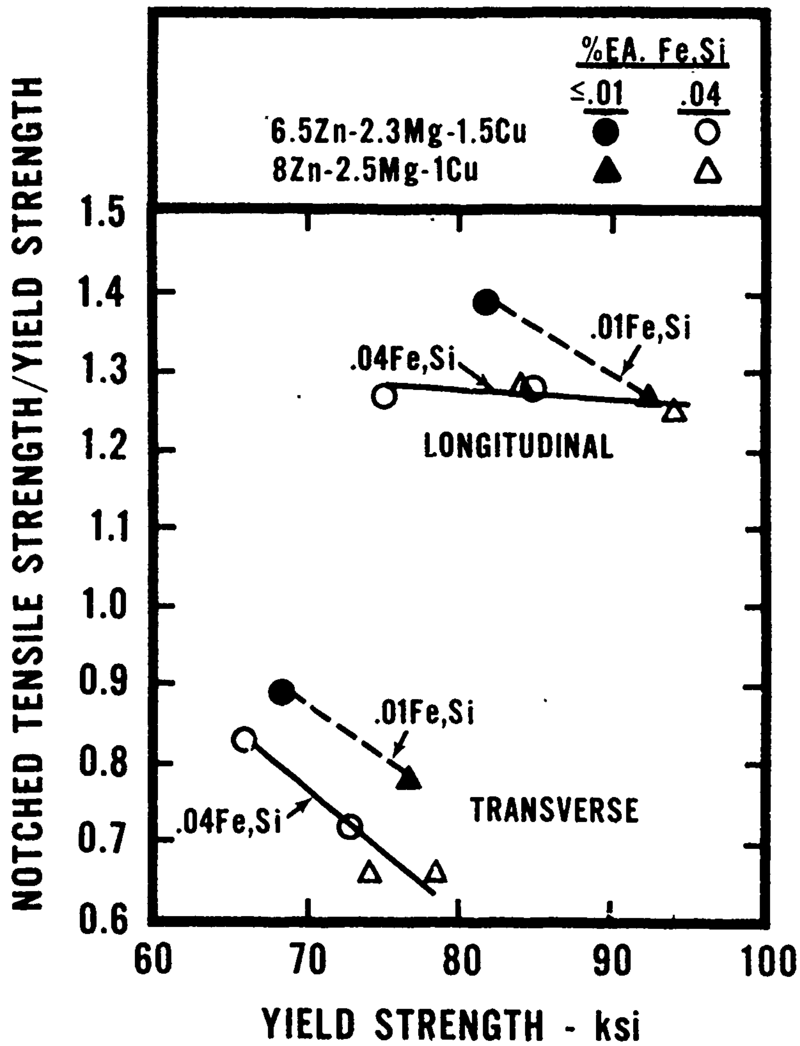


C.) "RET" PREHEAT METHOD
RETORT WITH FLOWING NITROGEN



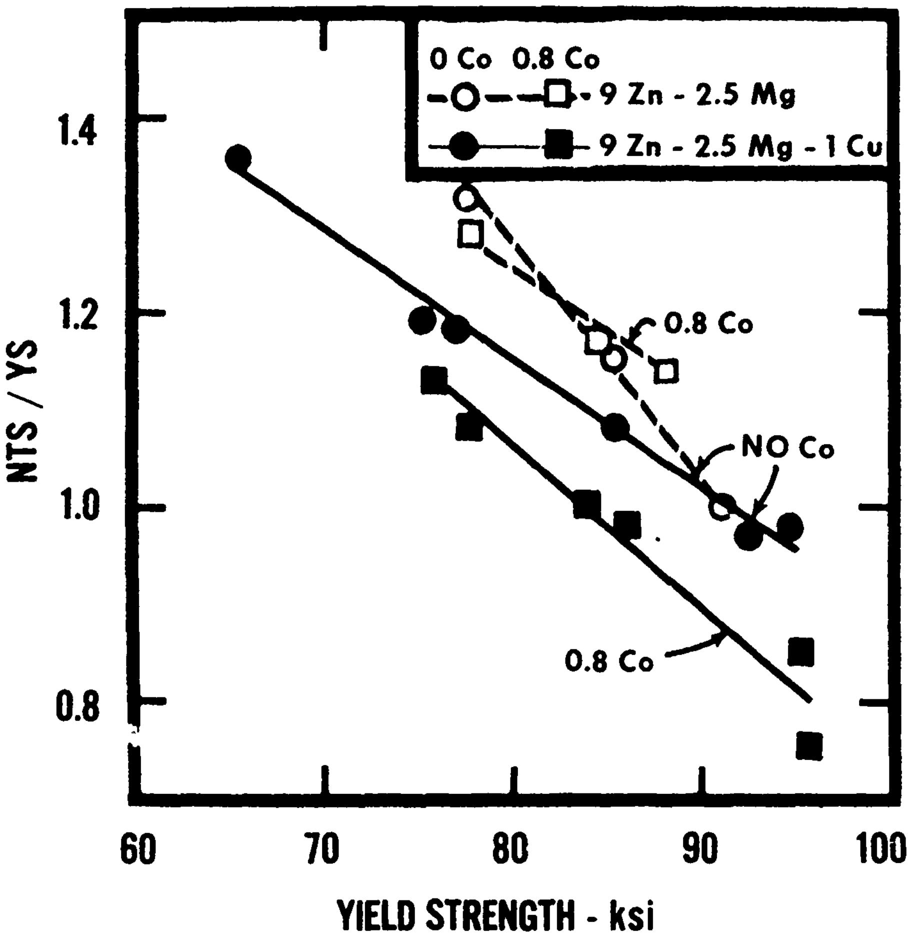
RETORT AND CAN COMPACT
PREHEATING SCHEMATICS

FIGURE 24



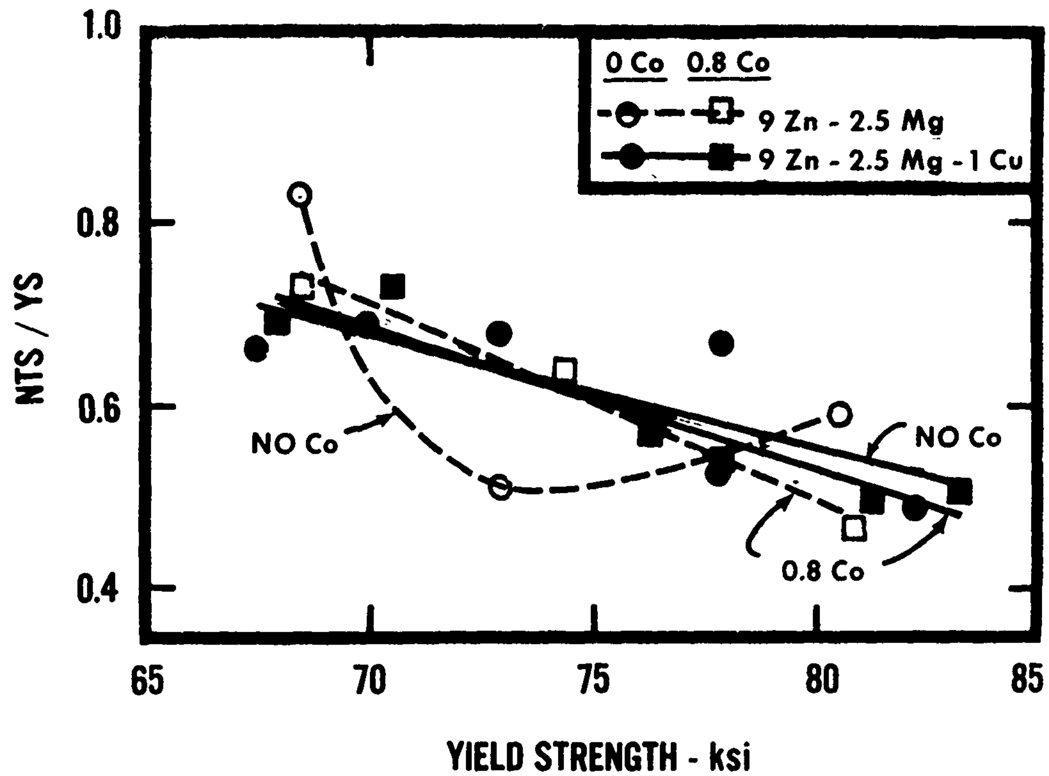
EFFECT OF REDUCED Fe AND Si ON FRACTURE TOUGHNESS OF P/M EXTRUSIONS. NOTE HIGHER NTS/YS FOR A SPECIFIED Y.S. WITH LOWER Fe AND Si AT UP TO 82 ksi Y.S.

FIGURE 25



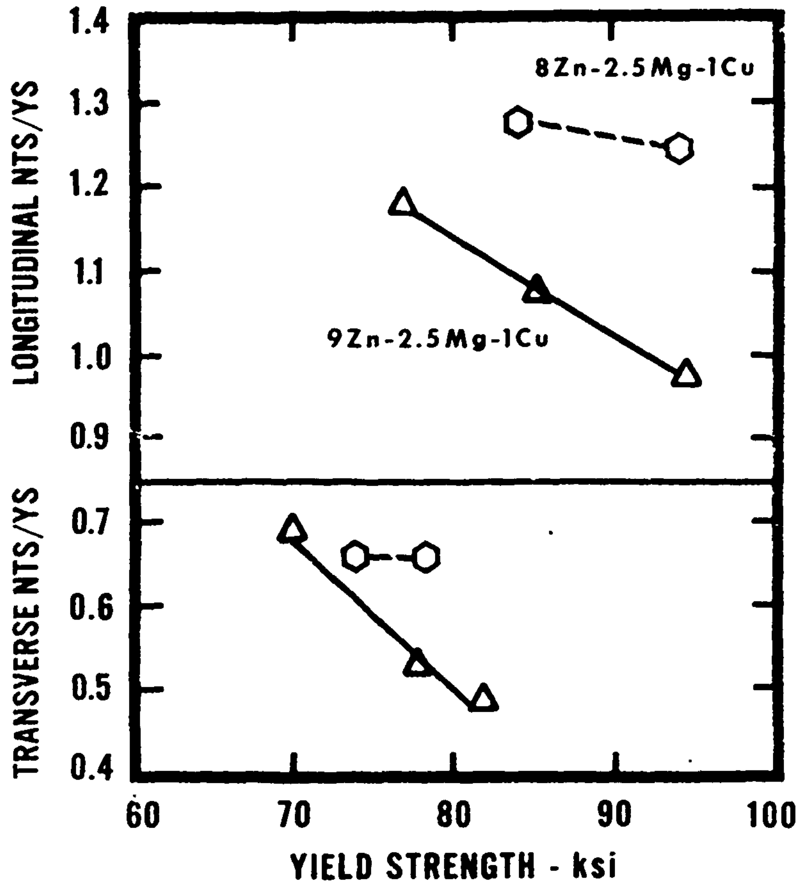
EFFECT OF Cu CONTENT ON THE LONGITUDINAL NTS / YS TO YIELD STRENGTH RELATION FOR EXTRUSIONS FROM 16μM (APD) POWDERS.

FIGURE 26



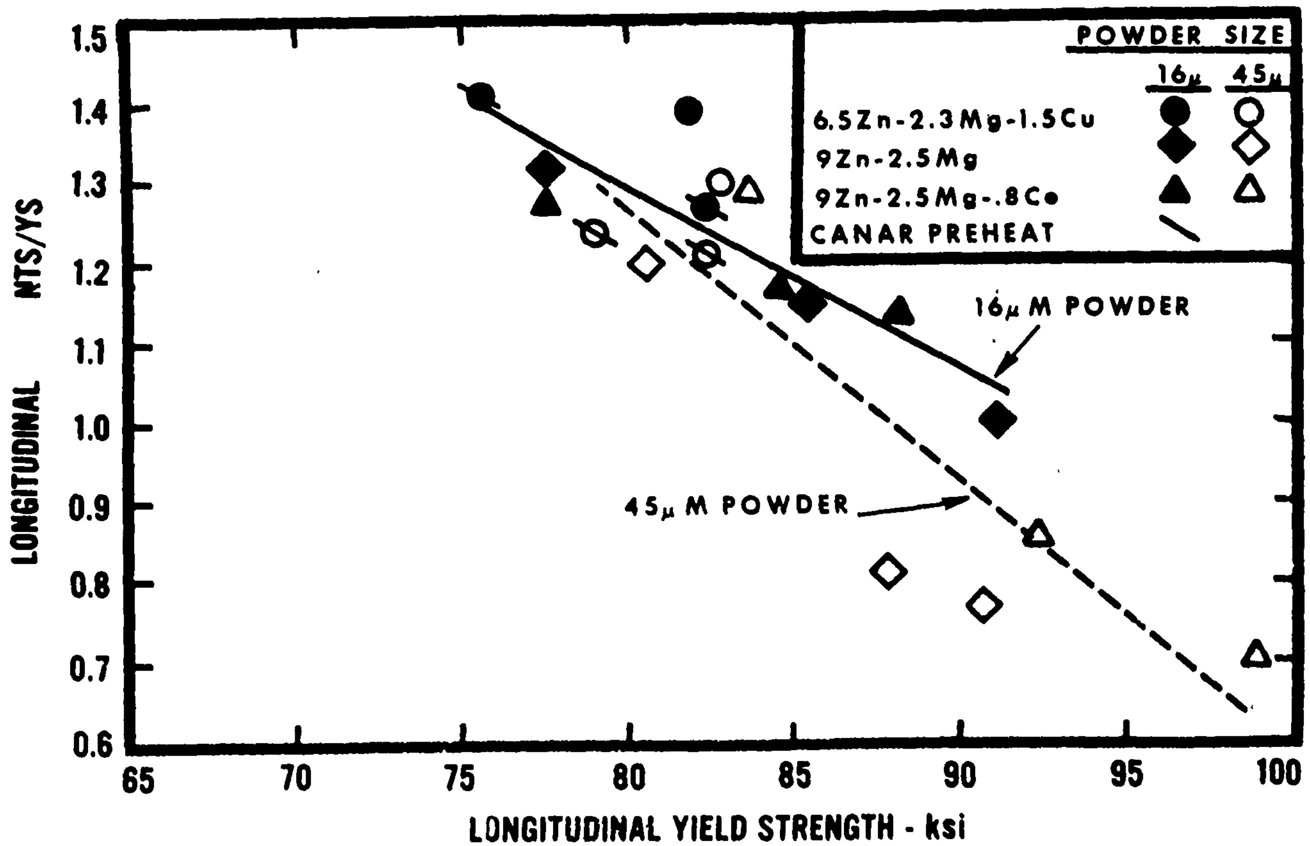
EFFECT OF Cu CONTENT ON THE TRANSVERSE NTS / YS TO YIELD STRENGTH RELATION FOR EXTRUSIONS FROM 16μM (APD) POWDERS.

FIGURE 27



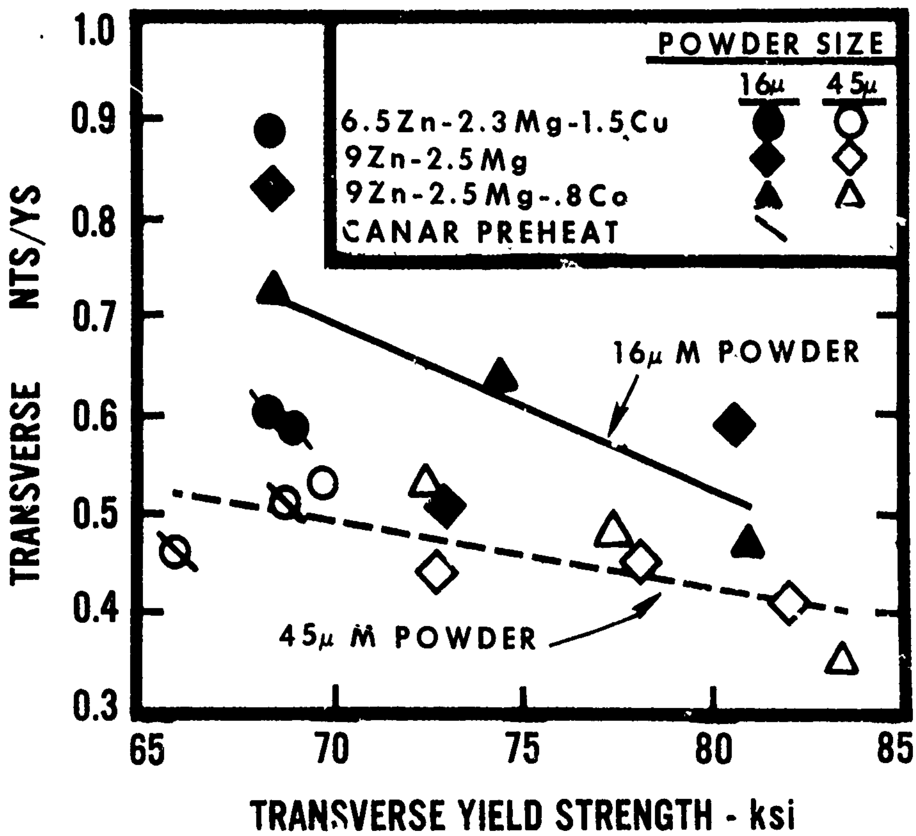
EFFECT OF INCREASING Zn ON FRACTURETOUGHNESS OF P/M EXTRUSIONS. NOTE: DECREASE IN NTS/YS AT ANY CONSTANT STRENGTH WITH INCREASING Zn FROM 8% TO 9%. 9Zn (REF.6).

FIGURE 28



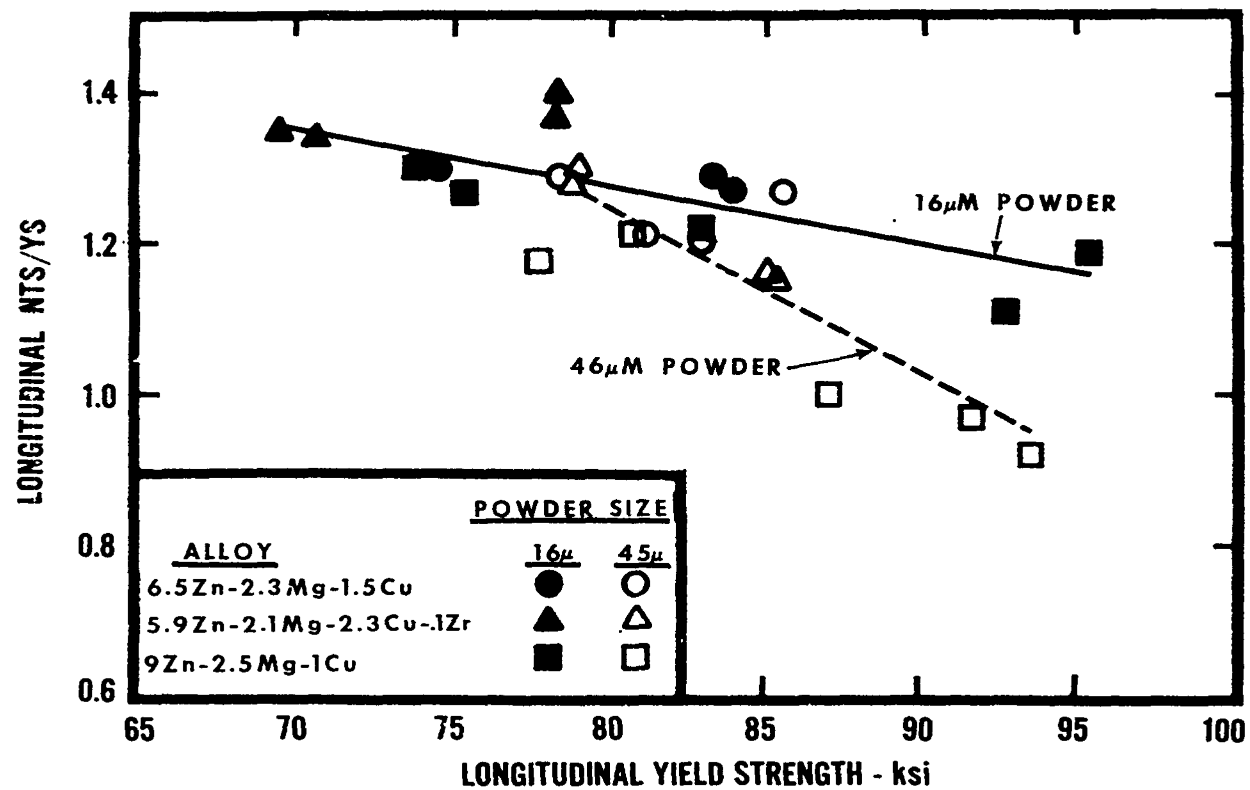
EFFECT OF POWDER SIZE ON THE LONGITUDINAL NTS/YS TO YIELD STRENGTH RELATION FOR P/M EXTRUSIONS FROM ARGON PREHEATED COMPACTS (FCE PREHEAT)

FIGURE 29



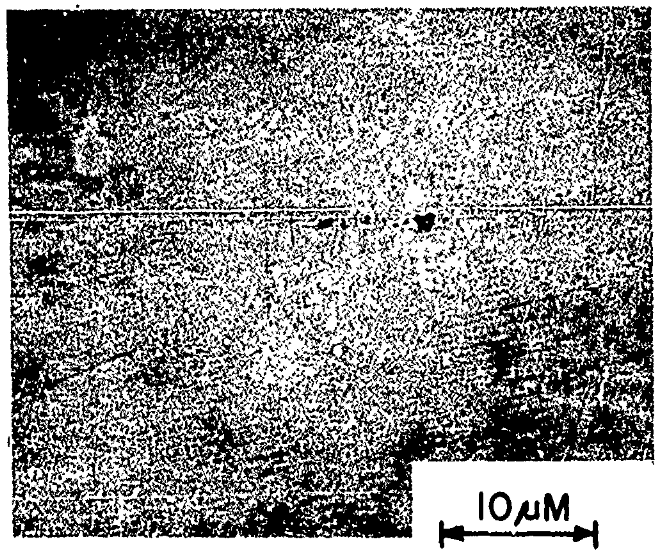
EFFECT OF POWDER SIZE ON THE TRANSVERSE NTS/YS TO YIELD STRENGTH RELATION FOR P/M EXTRUSIONS FROM ATMOSPHERE FURNACE PREHEATED COMPACTS (ARGON FCE PREHEAT).

FIGURE 30



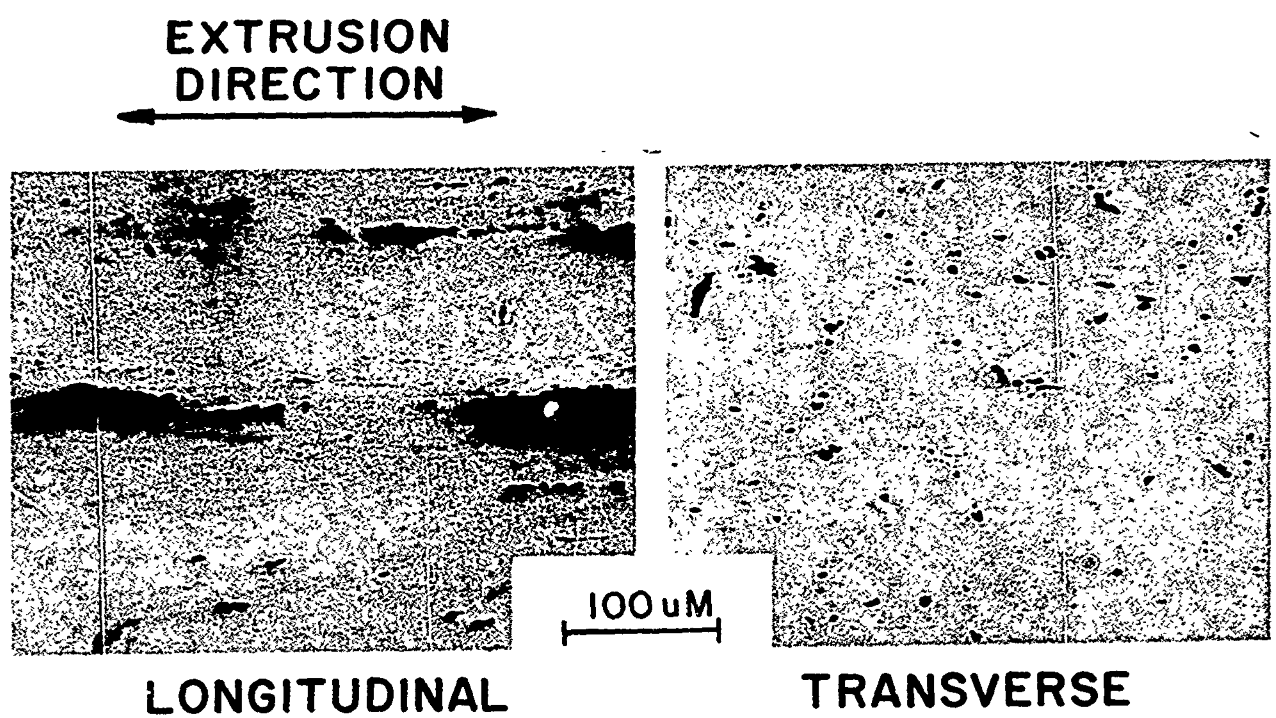
EFFECT OF POWDER SIZE ON THE LONGITUDINAL NTS/YS TO YIELD STRENGTH RELATION FOR P/M EXTRUSIONS FROM CAN/ARGON PREHEATED AND HOT PRESSED COMPACTS (CANAR PREHEAT).

FIGURE 31



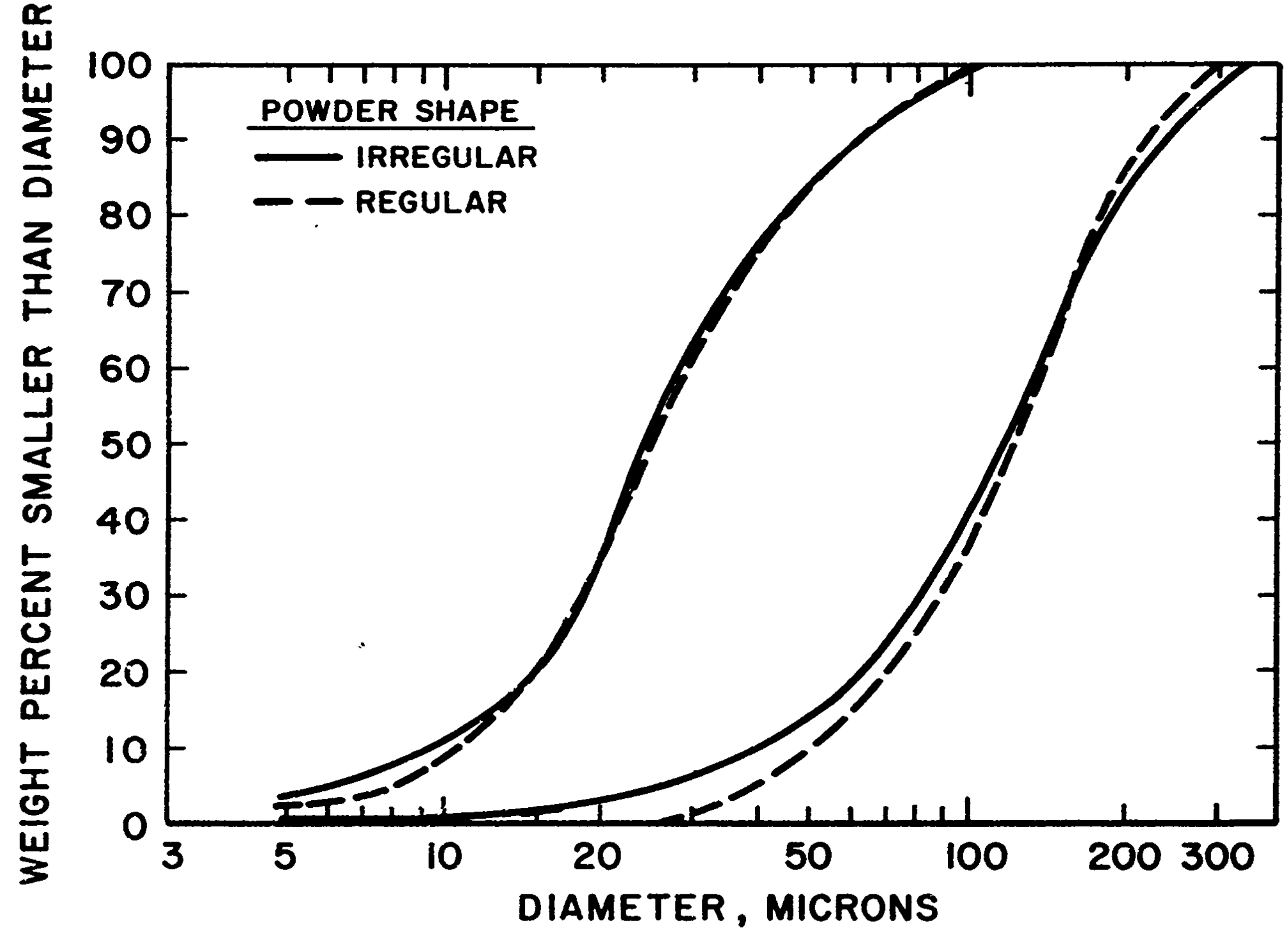
LONGITUDINAL SECTION OF 2 IN. DIAMETER EXTRUDED ROD MADE FROM FINE IRREGULAR POWDER. DENSITY = 0.1020 LB/CU. IN. 2000X, SEM UNETCHED.

FIGURE 32



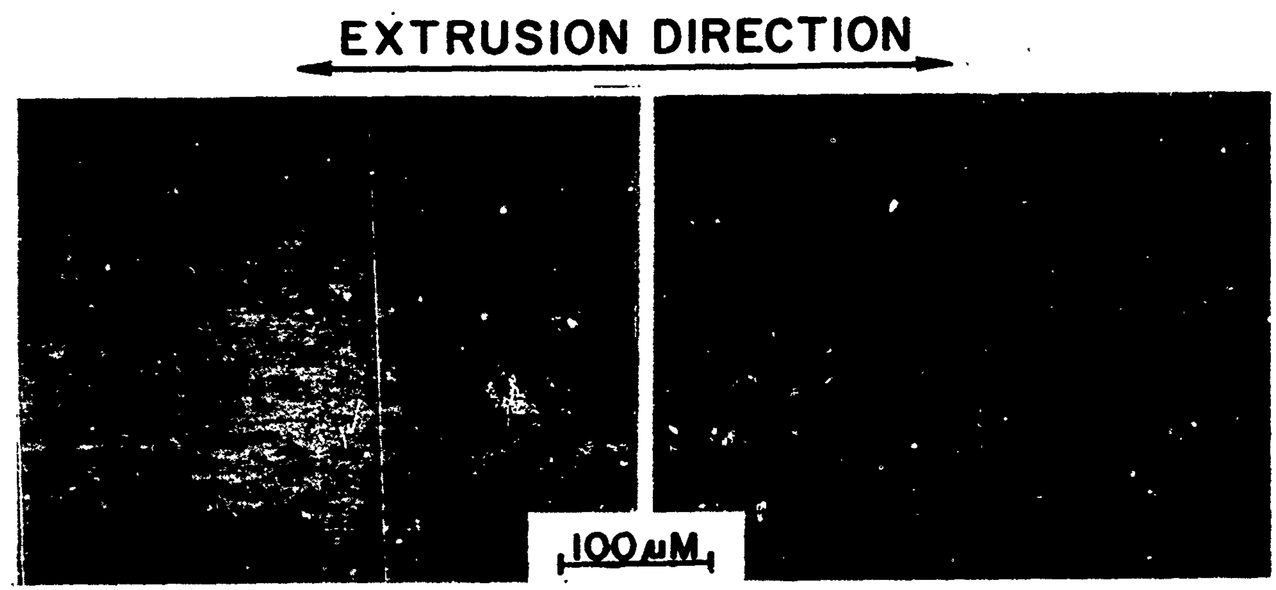
METAL FLOW DIRECTION VERSUS POROSITY

FIG. 33



PARTICLE SIZE DISTRIBUTION OF Al - 6.4 Zn - 2.2 Mg - 1.5 Cu ALLOY

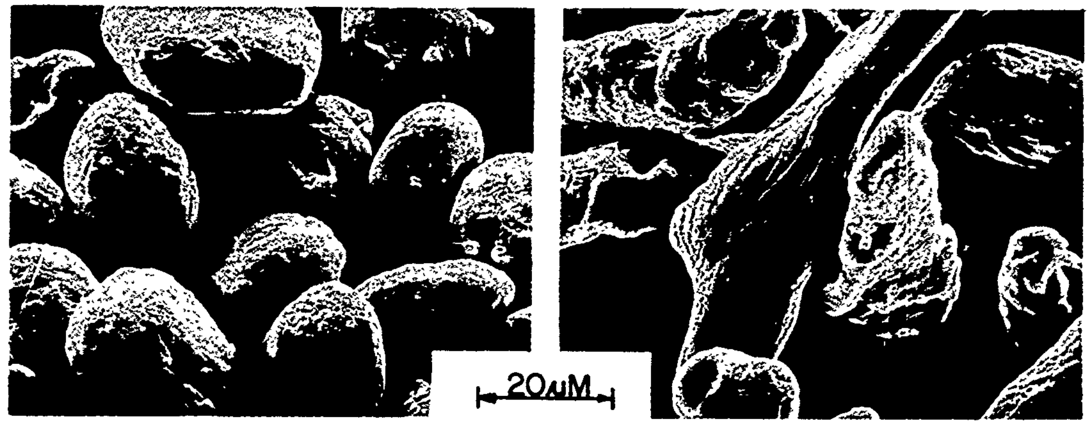
FIGURE 34



FINE IRREGULAR POWDER EXTRUSION PROPERTIES:	COARSE IRREGULAR POWDER EXTRUSION PROPERTIES:
DENSITY = 0.1020 LB/CU.IN.	DENSITY = 0.1015 LB/CU.IN.
TRANSVERSE ELONG. = 9 %	TRANSVERSE ELONG. = 2 %
TRANSVERSE NTS/YS = 0.89	TRANSVERSE NTS/YS = 0.55

EFFECT OF POWDER SIZE ON VOID SIZE OF EXTRUSIONS FROM FCE PREHEATED COMPACTS. 200X, SEM UNETCHED.

FIG. 35

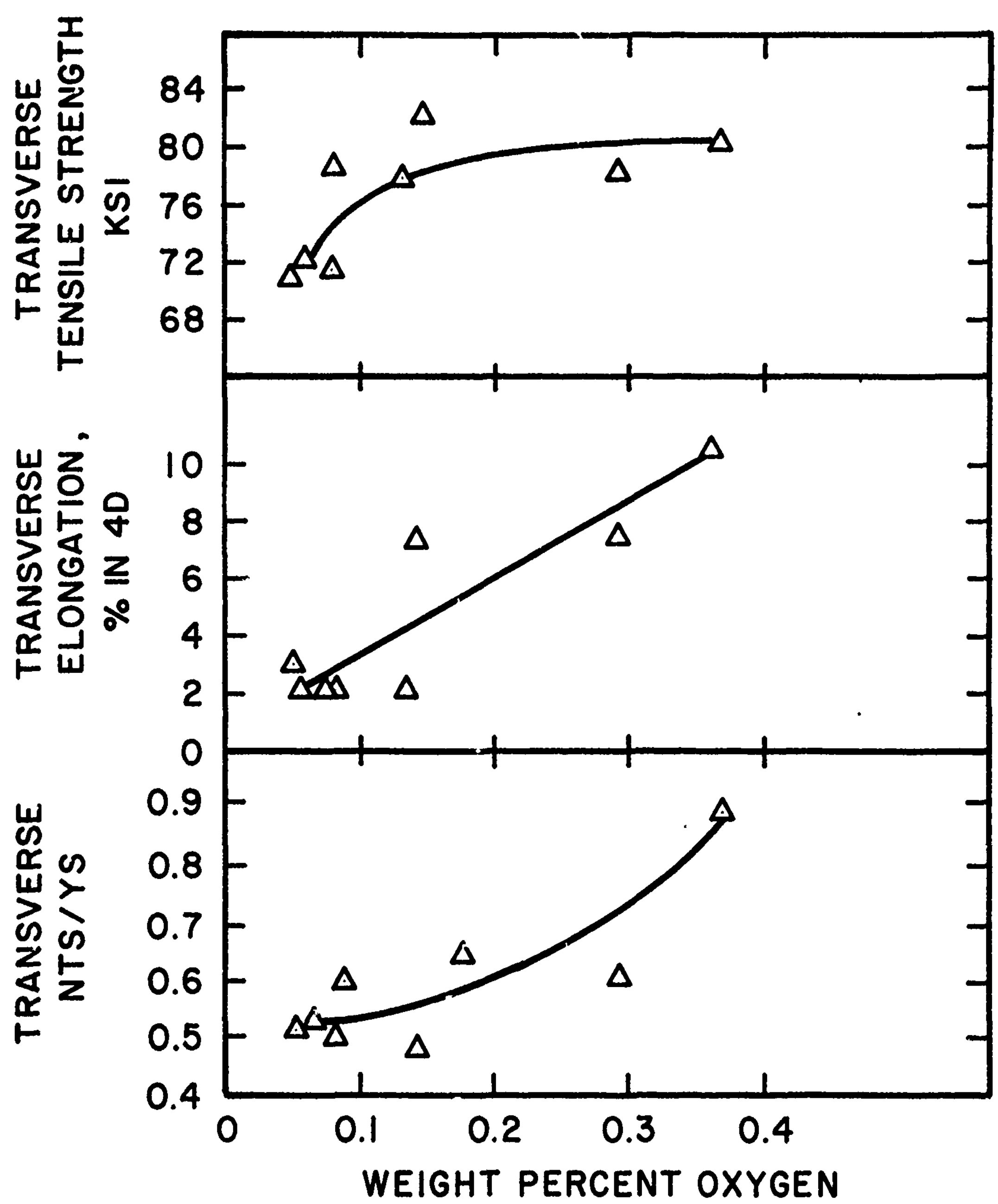


A. POWDER PARTICLES OF $-30+20 \mu M$ SIZE RANGE. NOTE SMOOTHNESS AND REGULAR SHAPE. 1000X

B. POWDER PARTICLES OF $-30+20 \mu M$ SIZE RANGE. NOTE IRREGULAR SHAPE AND SURFACE IRREGULARITIES. 1000X

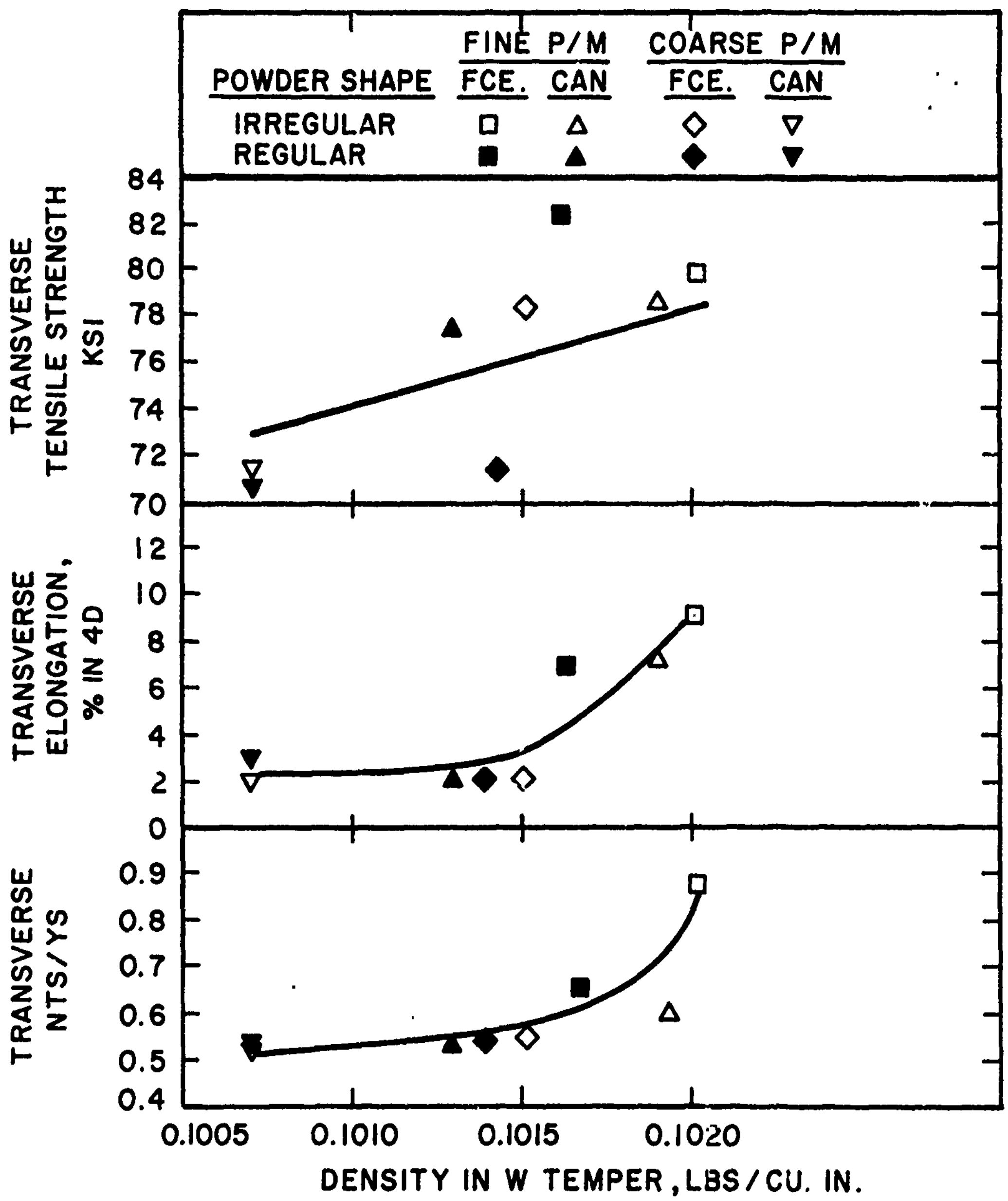
REGULAR AND IRREGULAR SHAPED ATOMIZED
Al - 6.5 Zn - 2.3 Mg - 1.5 Cu ALLOY POWDERS

FIGURE 36



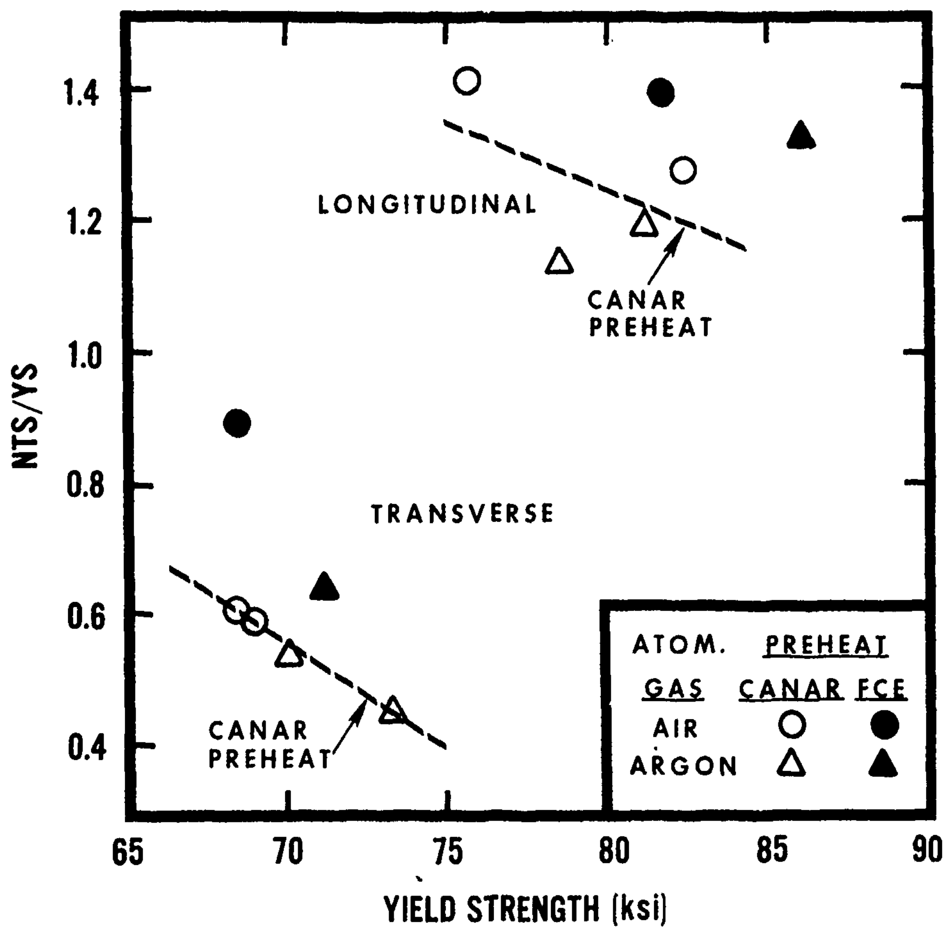
EFFECT OF OXYGEN CONTENT ON TRANSVERSE PROPERTIES OF P/M EXTRUSIONS.

FIGURE 37



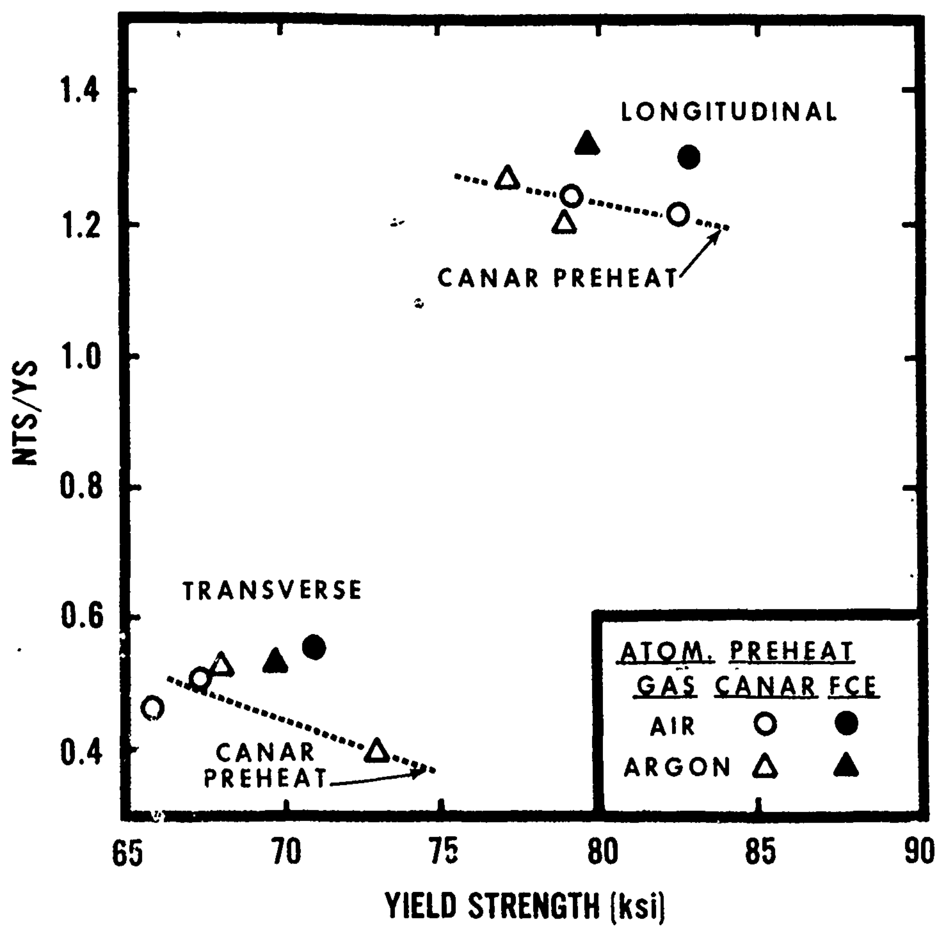
EFFECT OF DENSITY ON TRANSVERSE MECHANICAL PROPERTIES OF Al-6.4 Zn-2.3 Mg-1.5 Cu P/M EXTRUSIONS.

FIGURE 38



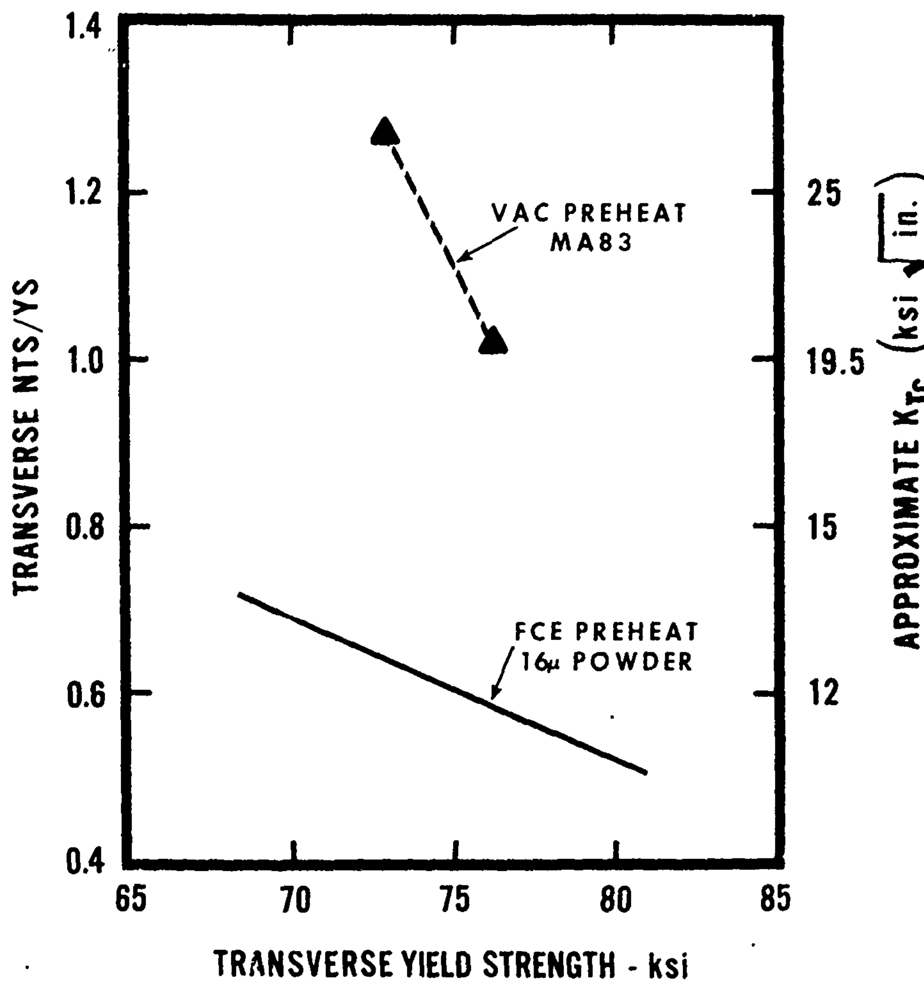
EFFECT OF POWDER ATOMIZING ATMOSPHERE ON THE LONGITUDINAL AND TRANSVERSE NTS/YS TO YIELD STRENGTH RELATIONSHIPS FOR HIGH PURITY Al-6.5 Zn-2.3 Mg-1.5 Cu EXTRUSIONS FROM FINE POWDER (15-20μM APD)

FIGURE 39



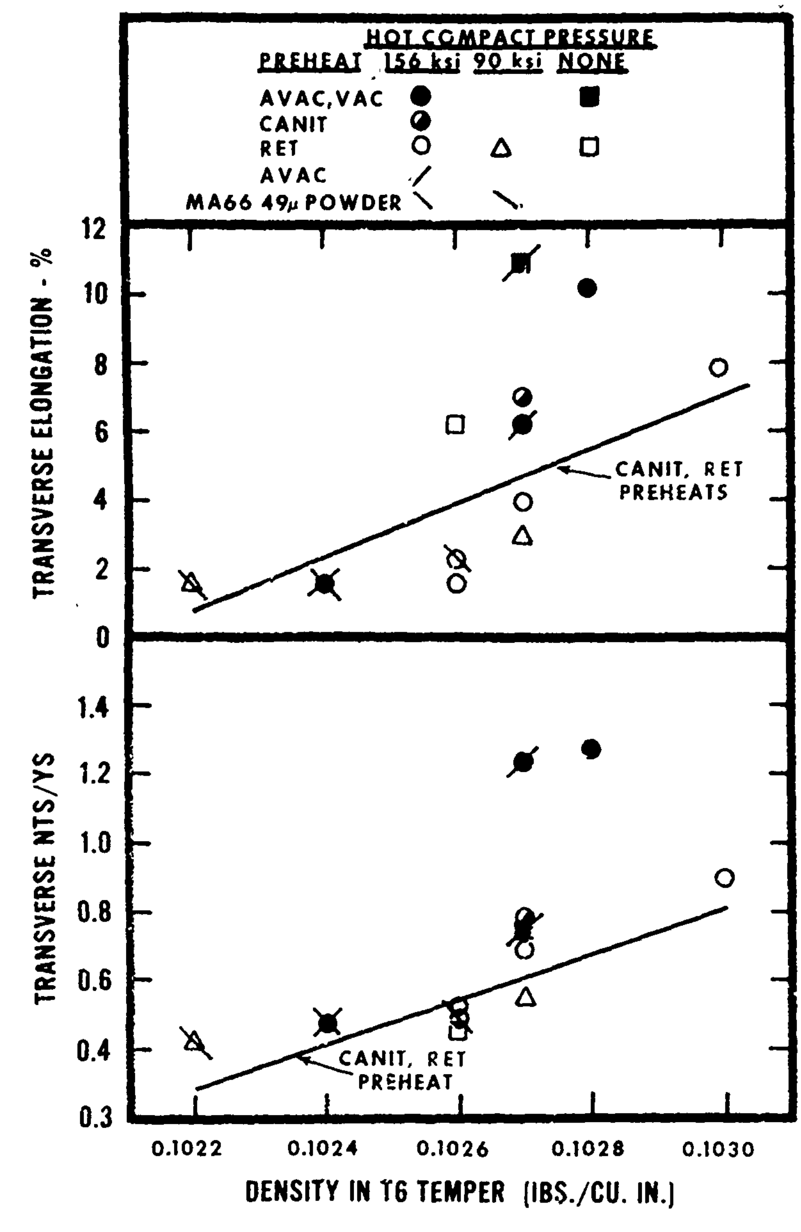
EFFECT OF POWDER ATOMIZING ATMOSPHERE ON THE LONGITUDINAL AND TRANSVERSE NTS/YS TO YIELD STRENGTH RELATIONSHIPS FOR HIGH PURITY Al-6.5 Zn-2.3 Mg-1.5 Cu EXTRUSIONS FROM COARSE POWDER (45-51 μM APD)

FIGURE 40



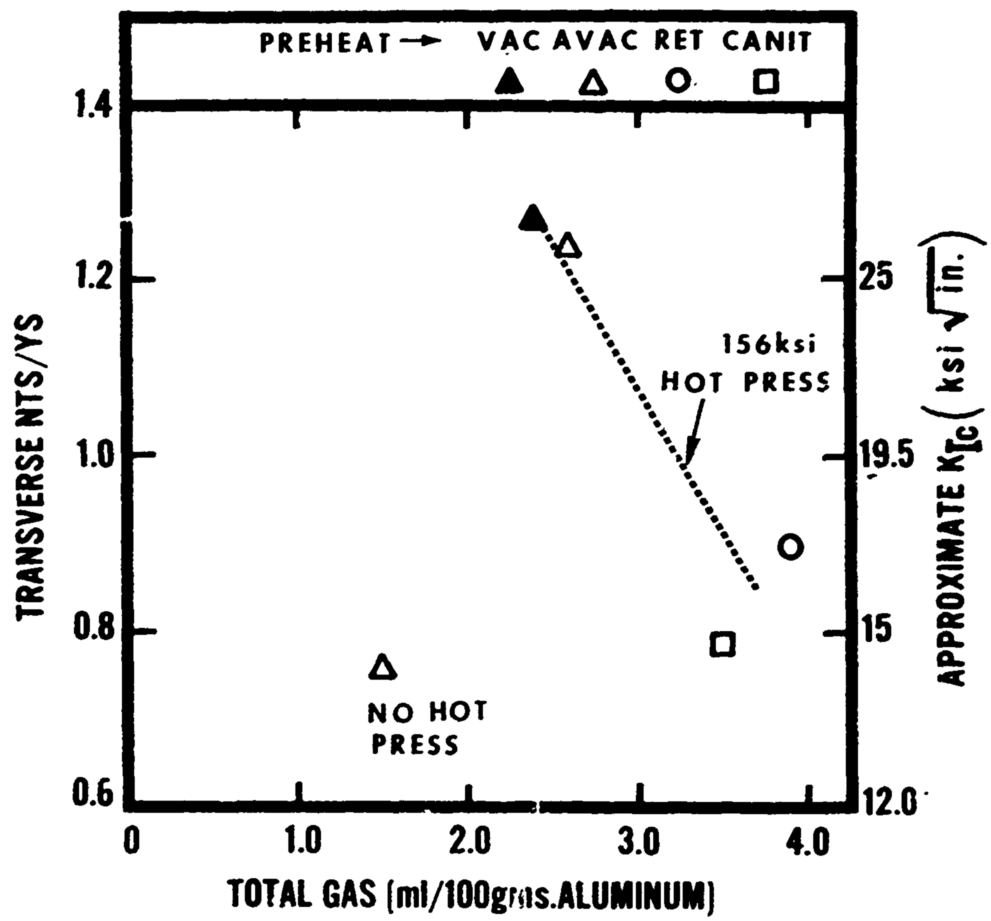
EFFECT OF VACUUM PREHEAT ON THE TRANSVERSE NTS/YS TO YIELD STRENGTH RELATION FOR P/M EXTRUSIONS. COMPARED TO ARGON FCE PREHEAT (FROM FIGURE 30)

FIGURE 41



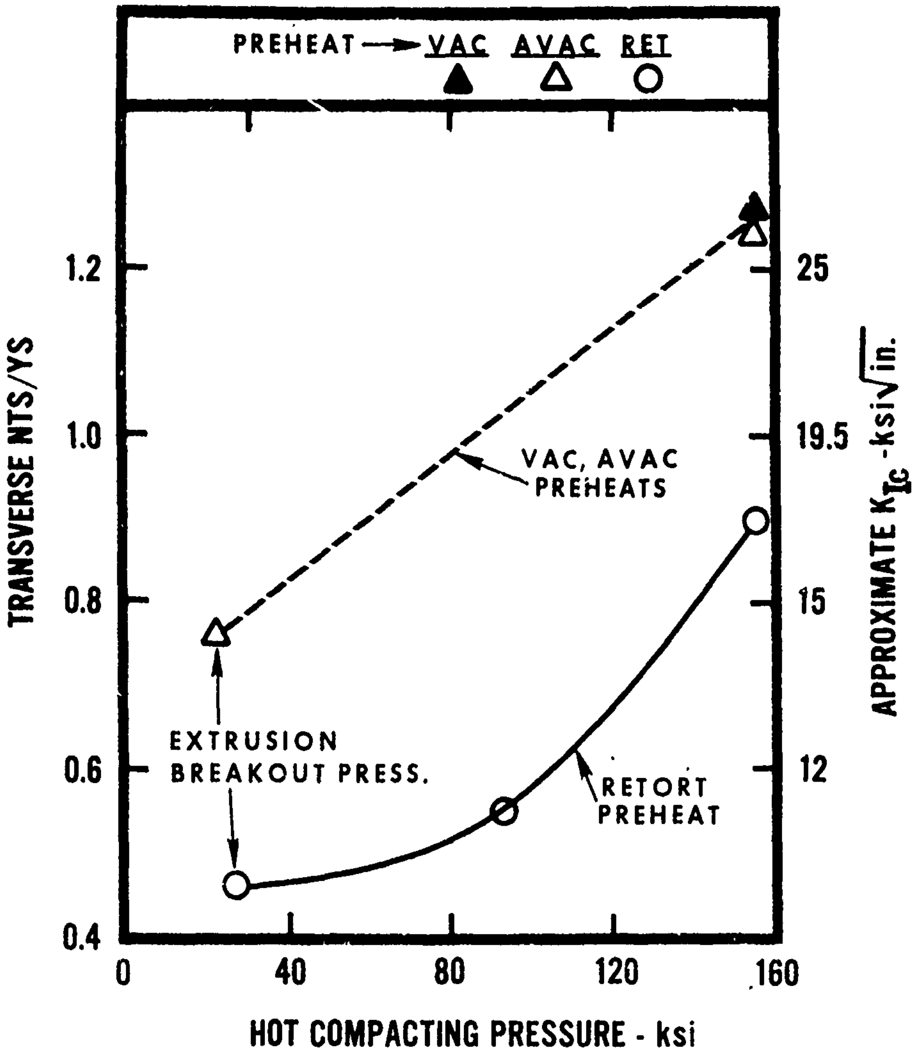
EFFECT OF DENSITY ON TRANSVERSE NTS/YS AND ELONGATION OF MA83 ALLOY EXTRUSIONS FROM VACUUM AND NITROGEN PREHEATED COMPACTS. ALL SECOND STEP AGED 6 HOURS AT 325°F

FIGURE 42



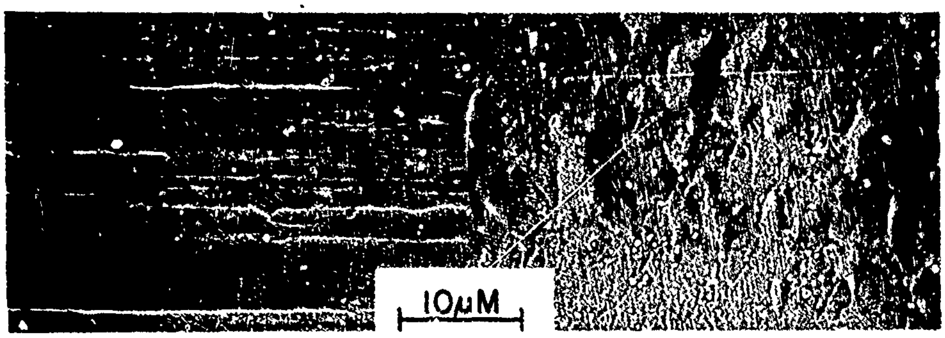
EFFECT OF TOTAL GAS CONTENT ON TRANSVERSE FRACTURE TOUGHNESS OF P/M MA83 EXTRUSIONS. FUSION GAS EXTRACTION AT 700°C.

FIGURE 43



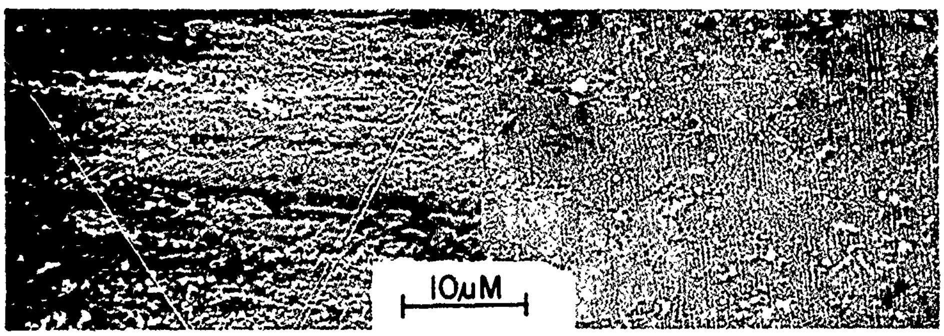
EFFECT OF HOT COMPACTING PRESSURE ON TRANSVERSE NTS/YS OF P/M MA83 EXTRUSIONS. ALL AGED 24 HOURS AT 250°F + 6 HOURS AT 325°F.

FIGURE 44



a. LONGITUDINAL VIEW: VAC PREHEATED MA83 EXTRUSION

b. TRANSVERSE VIEW: VAC PREHEATED MA83 EXTRUSION



c. LONGITUDINAL VIEW: CANIT PREHEATED MA83 EXTRUSION

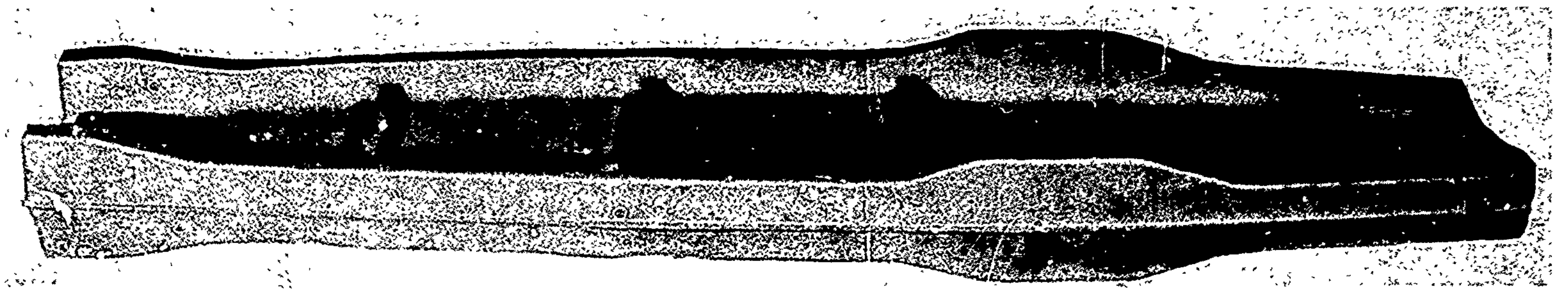
d. TRANSVERSE VIEW: CANIT PREHEATED MA83 EXTRUSION

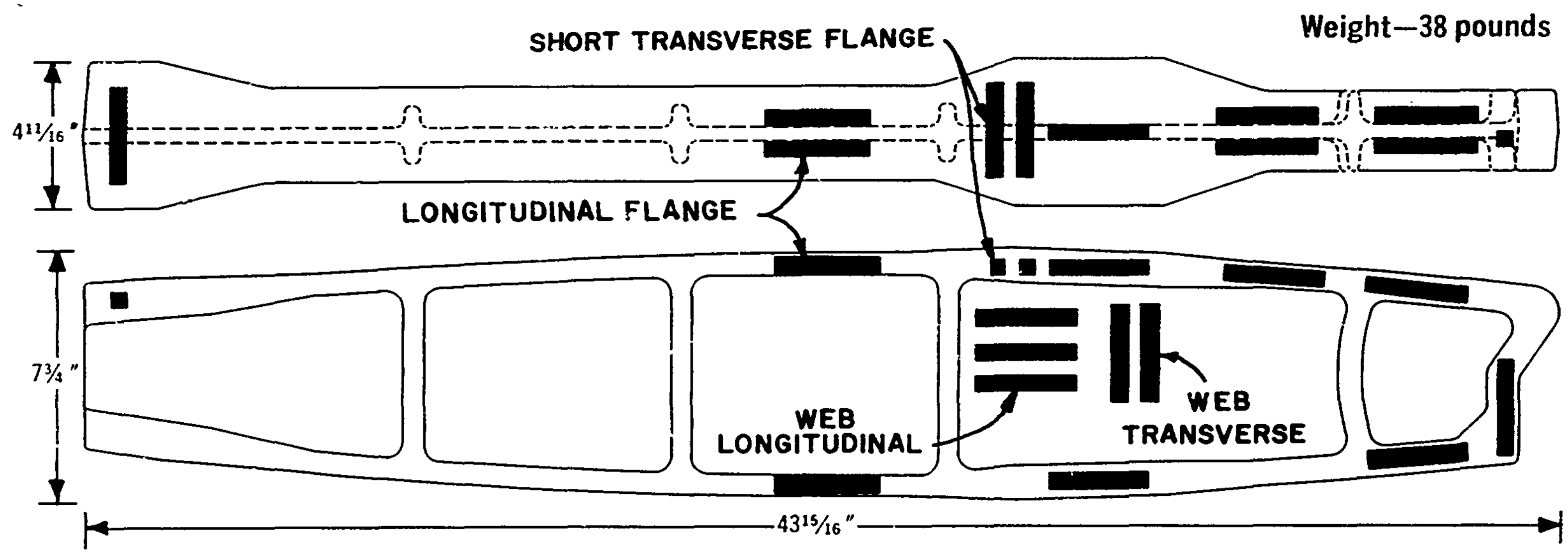
METALLURGICAL STRUCTURE COMPARISON OF MA83 OCTAGONAL EXTRUSIONS FROM COMPACTS PREHEATED IN VACUUM OR IN A CAN WITH NITROGEN.

FIG. 45

PRODUCTION SEQUENCE FOR P/M DIE FORGINGS
RIGHT TO LEFT: GREEN COMPACT; HOT
PRESSED COMPACT; EXTRUDED STOCK;
FORGING.

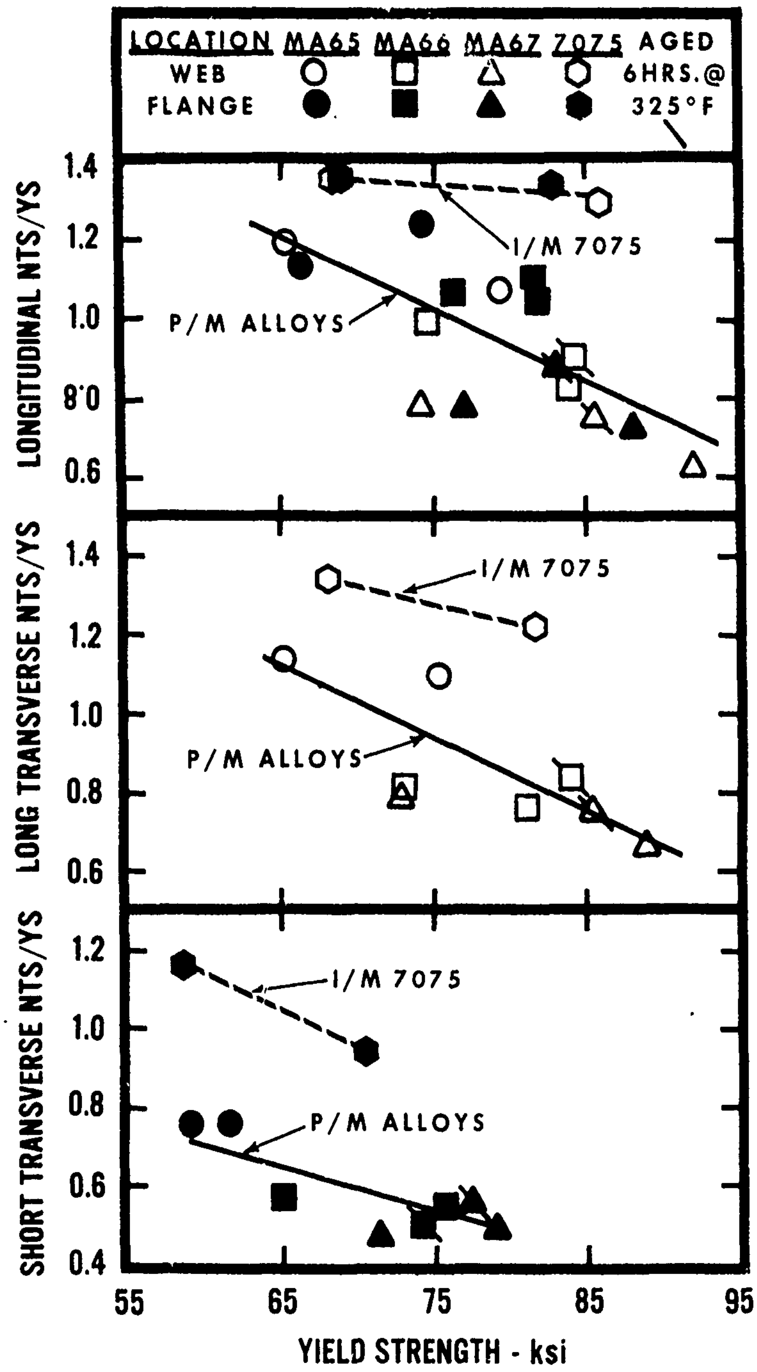
FIG. 46





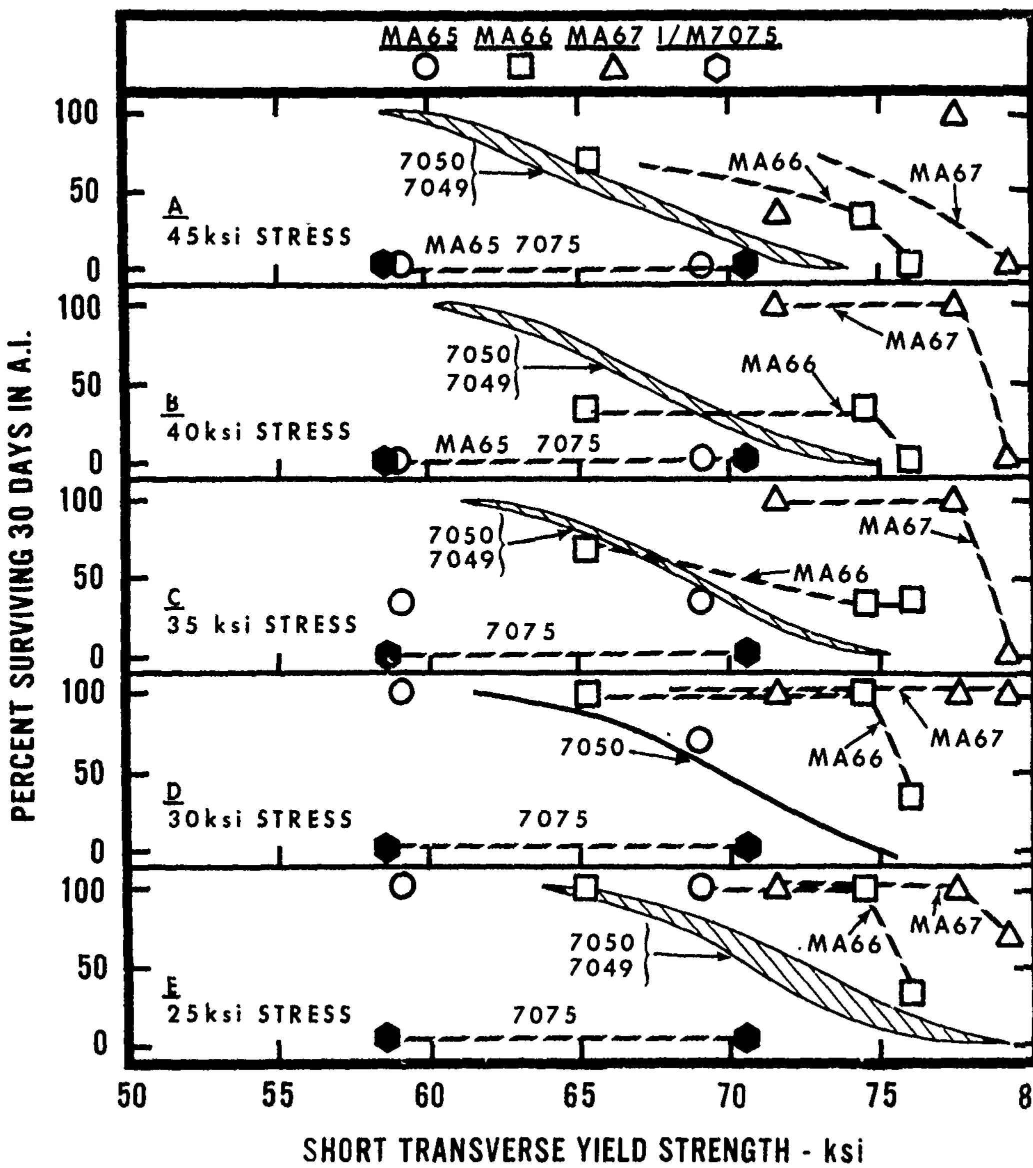
BOEING RIB FORGING
ALCOA DIE 9078

FIG. 47



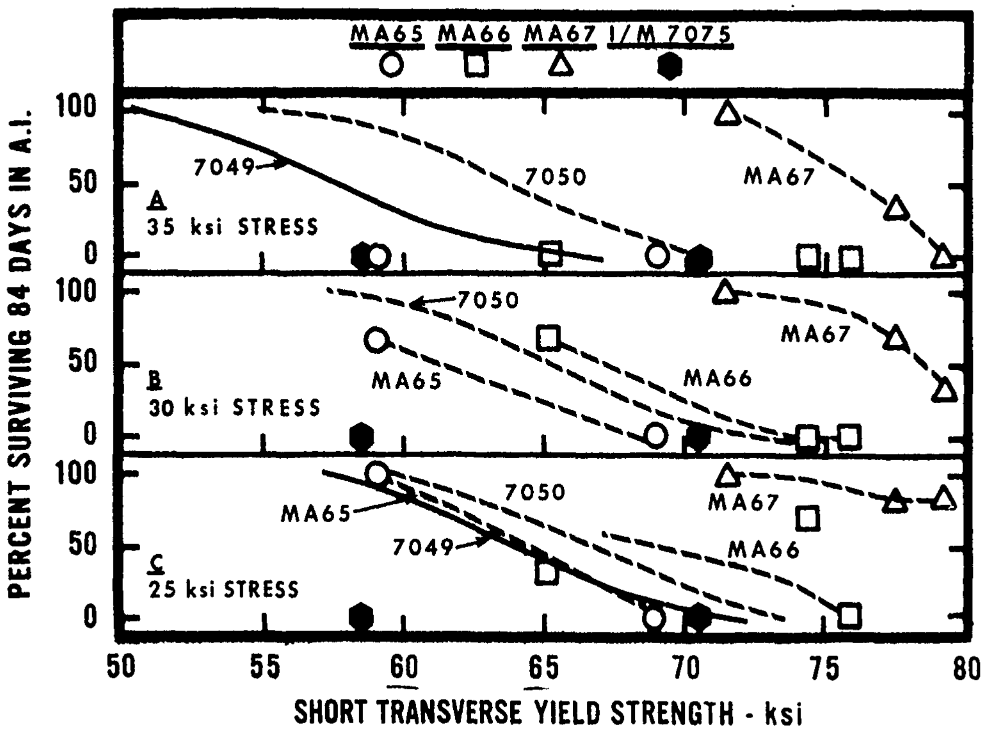
EFFECT OF YIELD STRENGTH ON FRACTURE TOUGHNESS (NTS/YS) OF P/M AND I/M 7075 DIE FORGINGS. (DIE 9078)

FIGURE 48



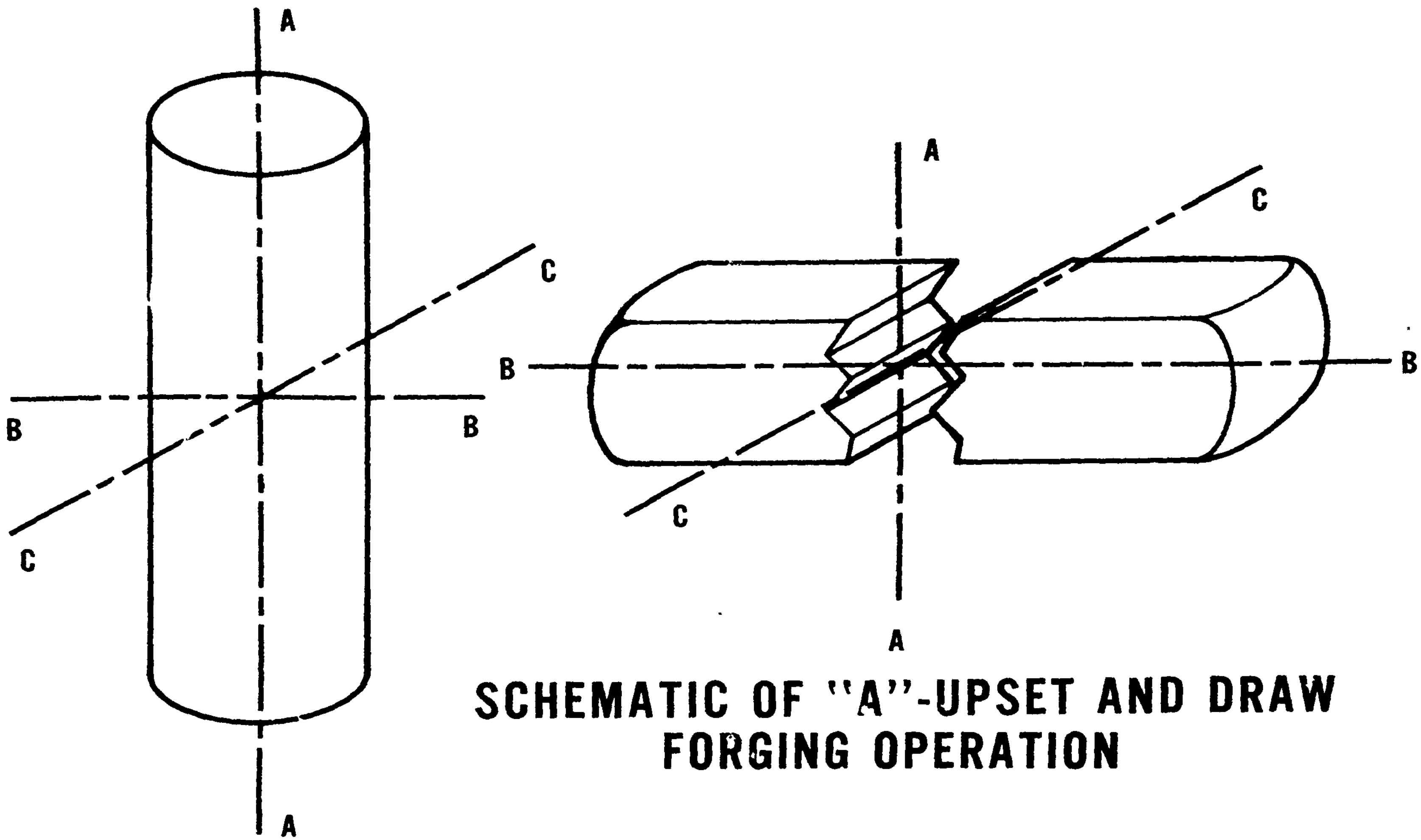
EFFECT OF STRENGTH AND APPLIED STRESS ON PERCENT SURVIVING 30 DAYS IN THE ALTERNATE IMMERSION STRESS CORROSION TEST. TENSILE BAR SPECIMENS FROM DIE FORGINGS.

FIGURE 49



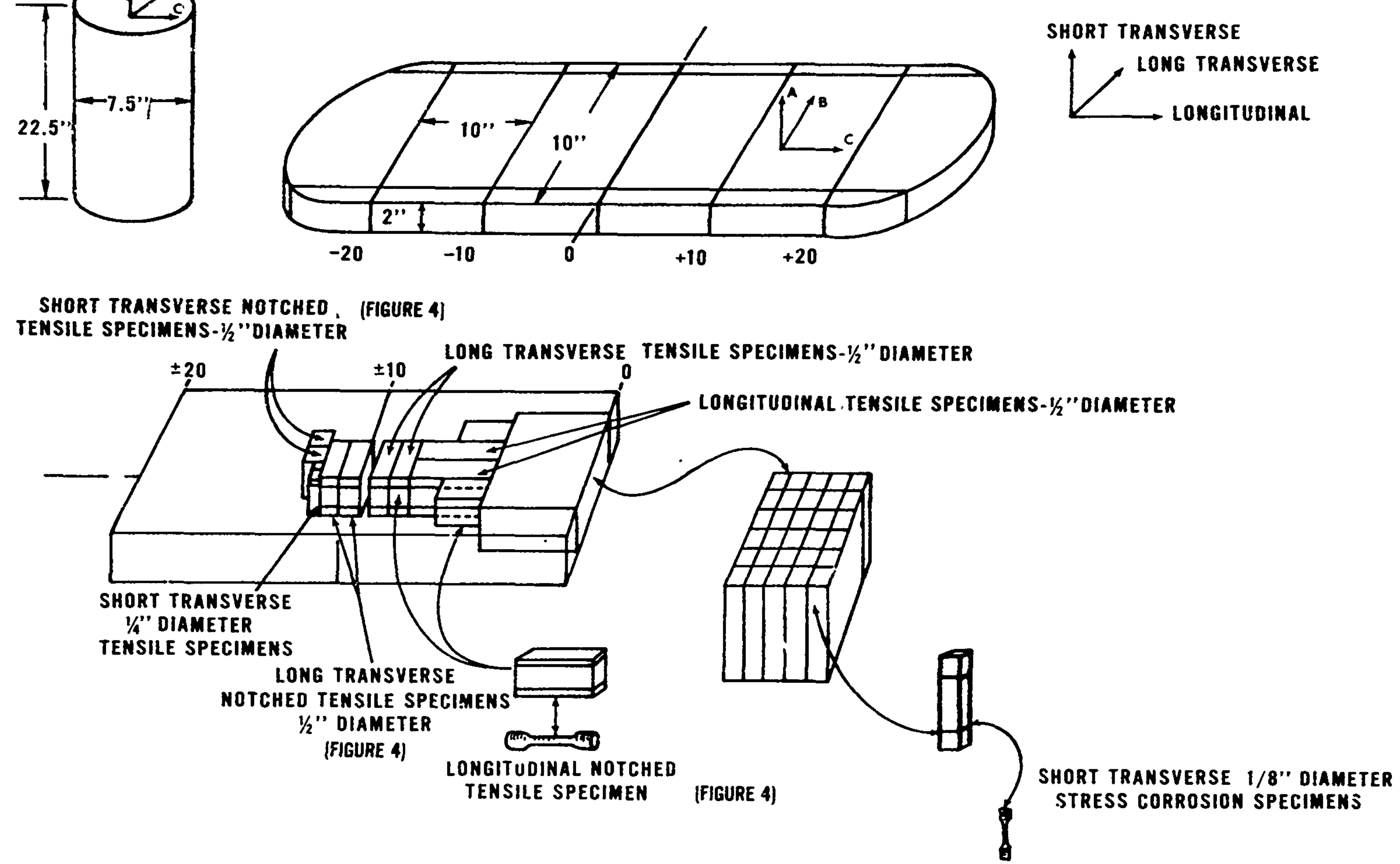
EFFECT OF STRENGTH AND APPLIED STRESS ON PERCENT SURVIVING 84 DAYS IN THE ALTERNATE IMMERSION STRESS CORROSION TEST. TENSILE BAR SPECIMENS FROM 9078 DIE FORGINGS.

FIGURE 50



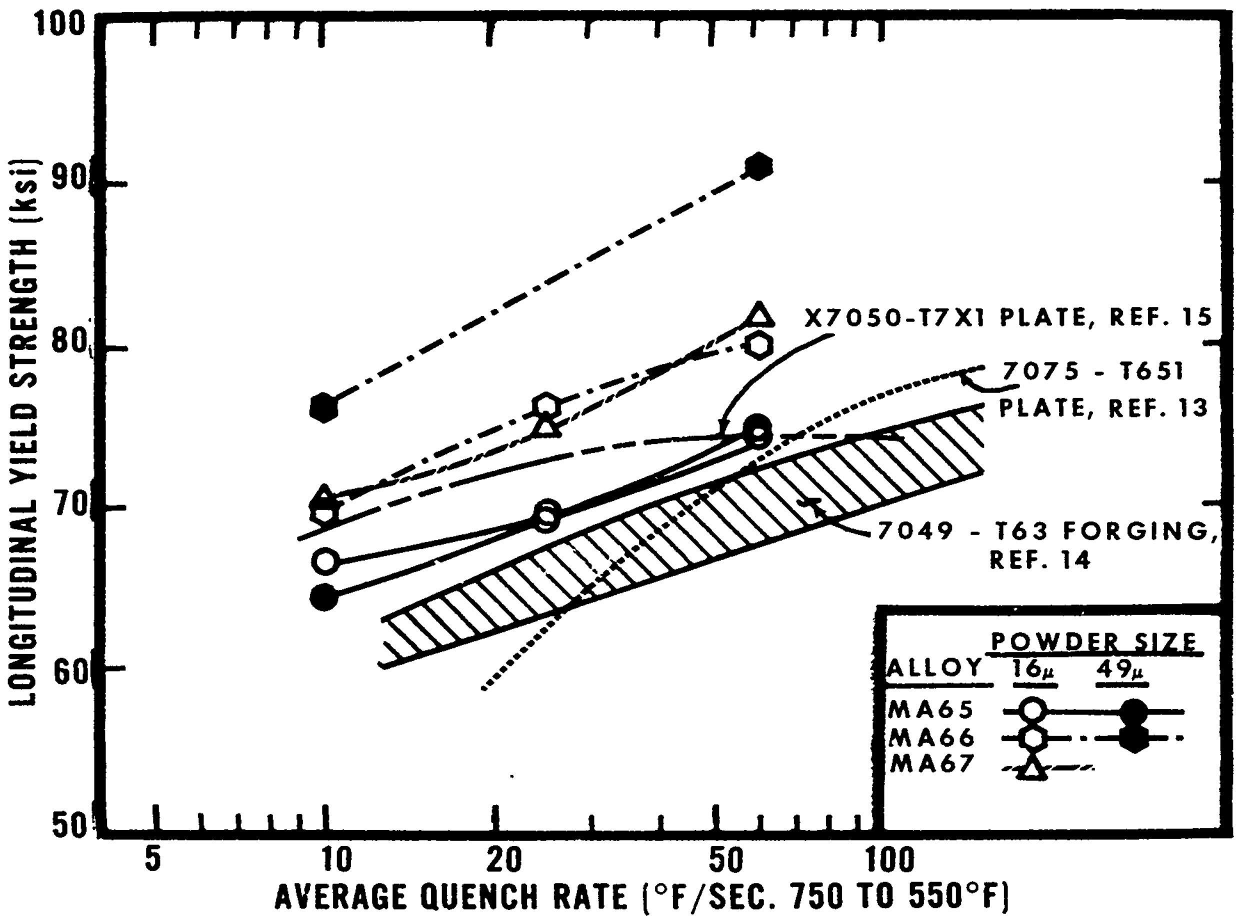
SCHEMATIC OF "A"-UPSET AND DRAW FORGING OPERATION

FIGURE 51



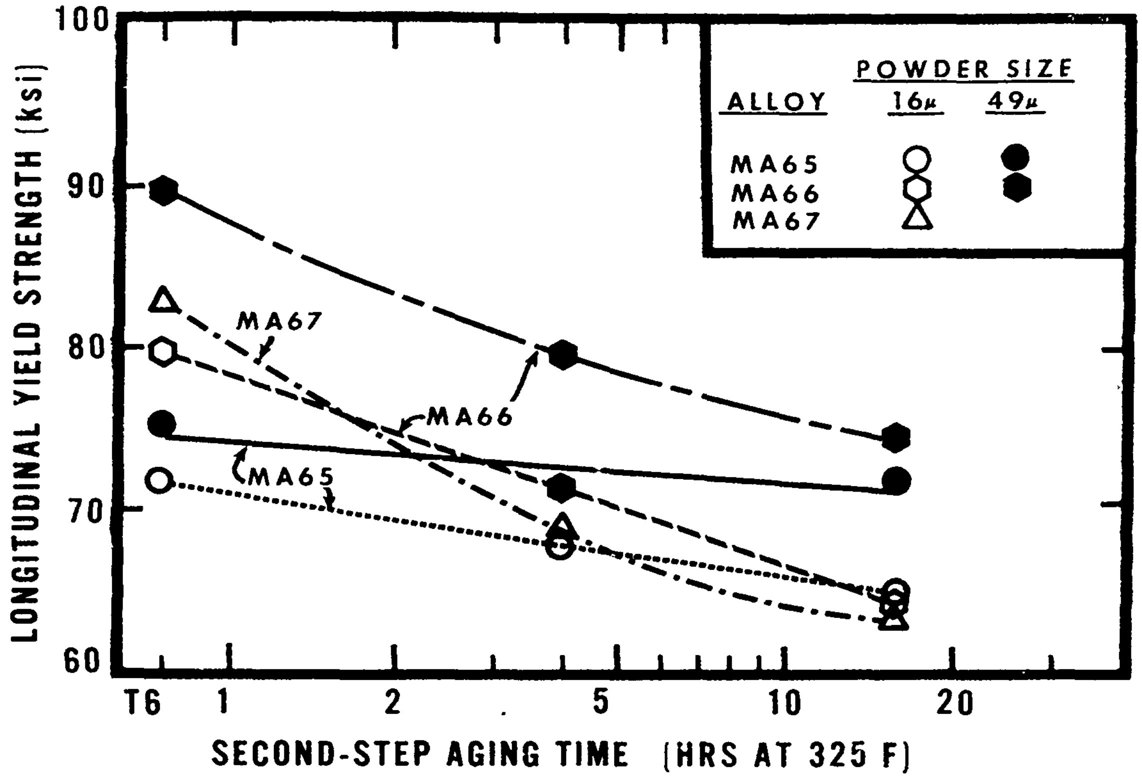
2 INCH THICK HAND FORGING SAMPLE LAYOUT

FIGURE 52



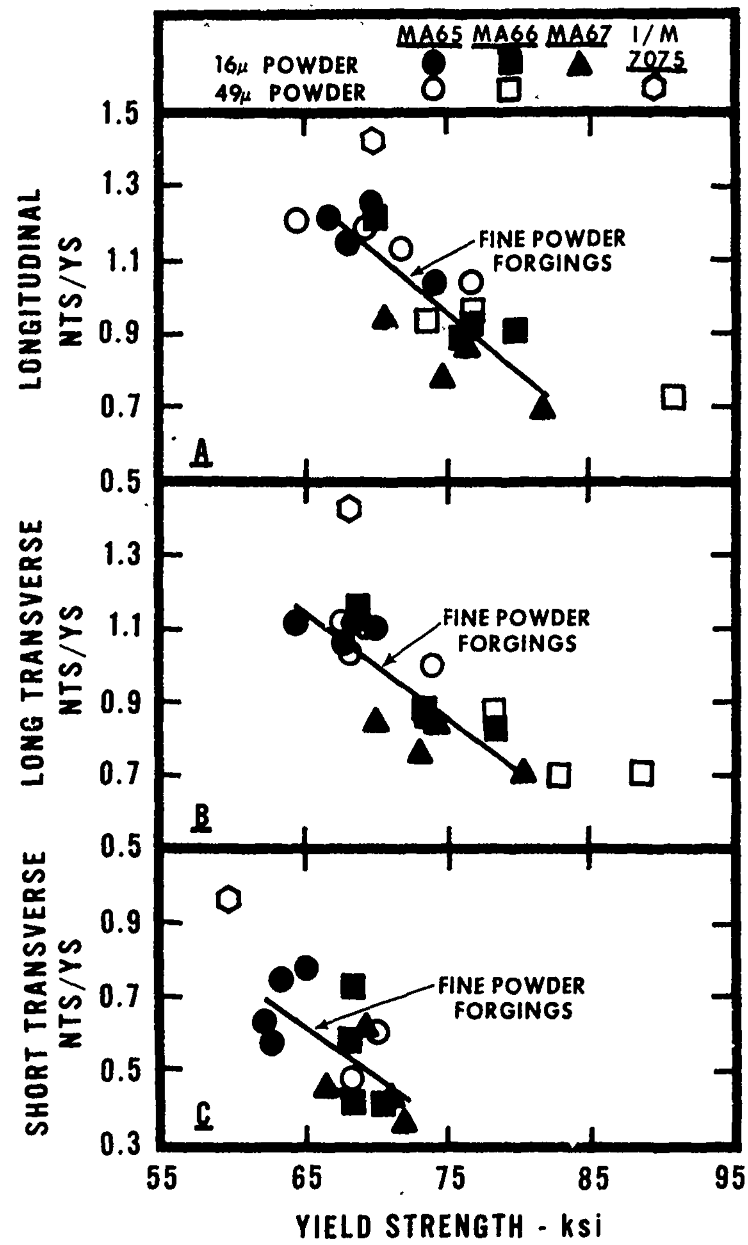
EFFECT OF QUENCH RATE ON LONGITUDINAL YIELD STRENGTH OF 2" THICK P/M FORGINGS

FIGURE 53



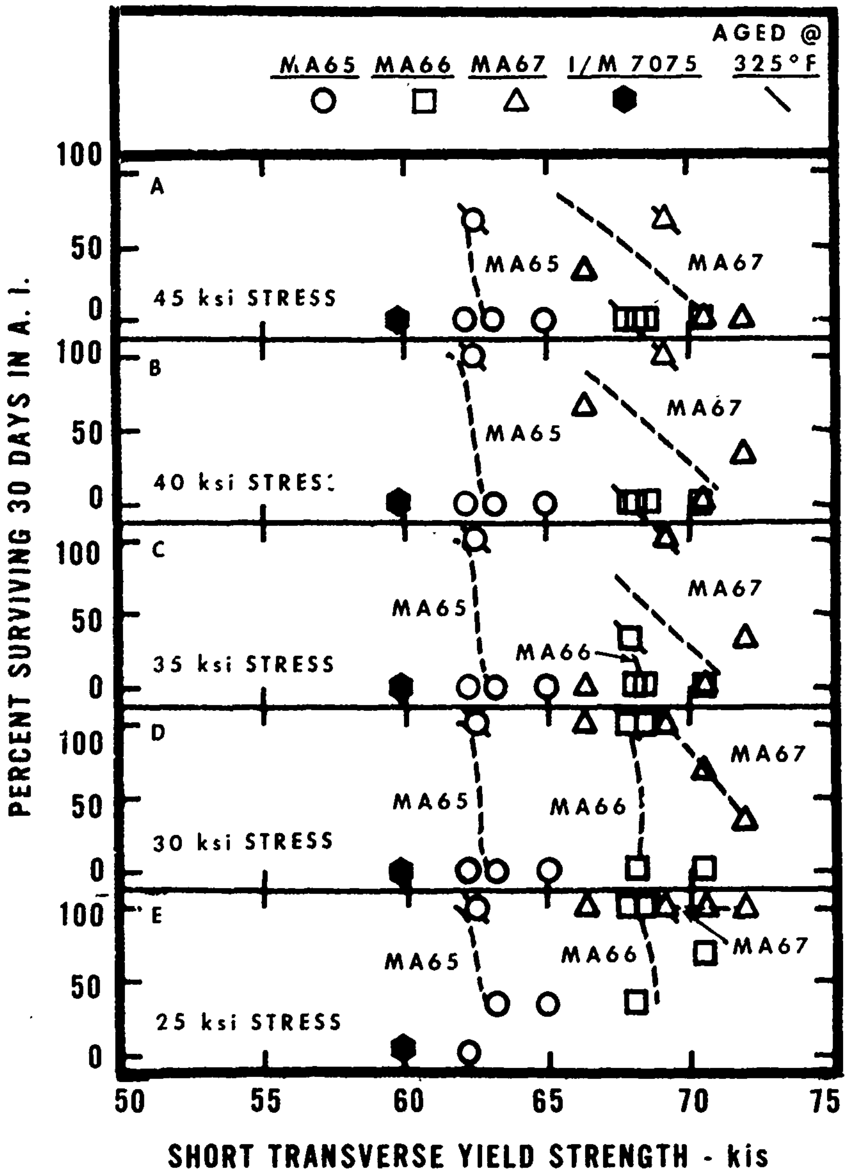
EFFECT OF SECOND-STEP AGING TIME ON LONGITUDINAL YIELD STRENGTH OF 2" THICK × 10" WIDE HAND FORGINGS. P/M HAND FORGINGS A-UPSET AND DRAW (L=15), COLD-WATER QUENCHED AND STRESS RELIEVED. FIRST-STEP AGED 24 HRS AT 250 F.

FIGURE 54



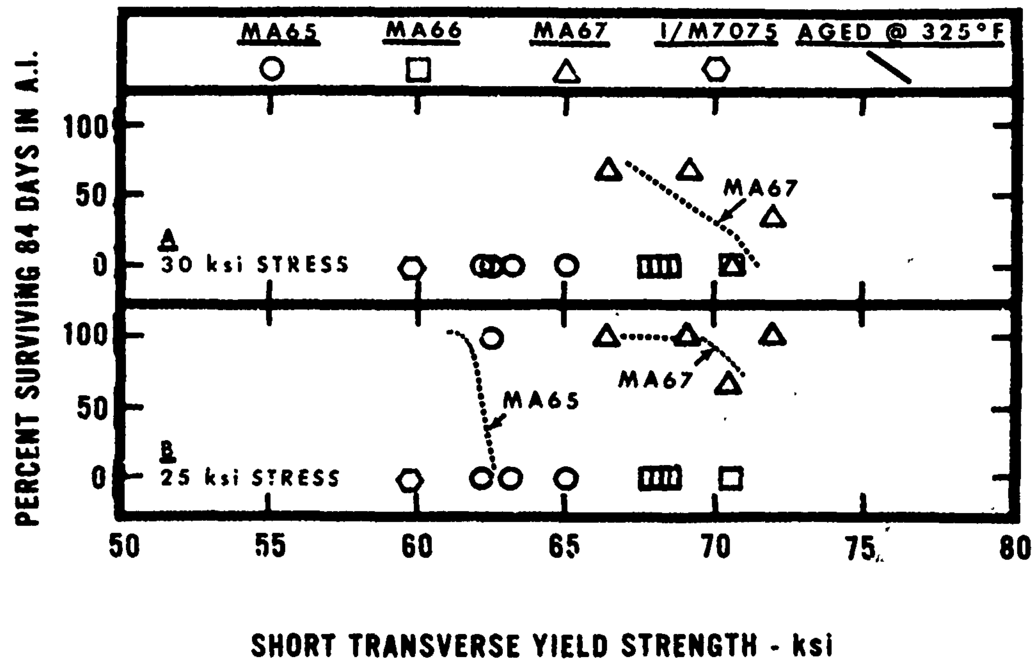
EFFECT OF YIELD STRENGTH ON FRACTURE TOUGHNESS (NTS/YS) OF P/M ALLOY AND I/M 7075 2-in. THICK HAND FORGINGS

FIGURE 55



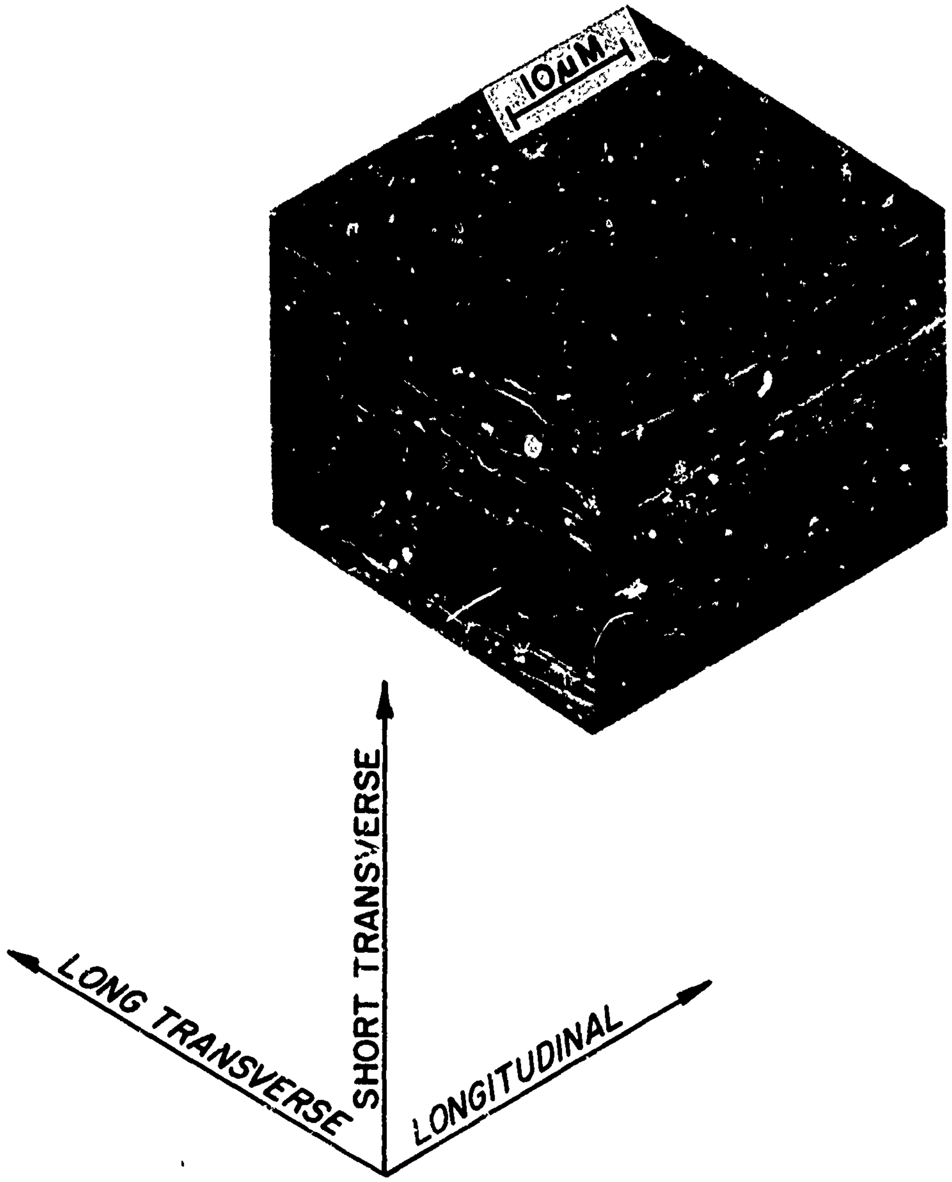
EFFECT OF YIELD STRENGTH AND APPLIED STRESS ON PERCENT SURVIVING 30 DAYS IN ALTERNATE IMMERSION SCC TEST. SHORT TRANSVERSE TENSILE BARS FROM 2" THICK P/M (OF 16μ POWDER) AND FROM I/M 7075 HAND FORGINGS.

FIGURE 56



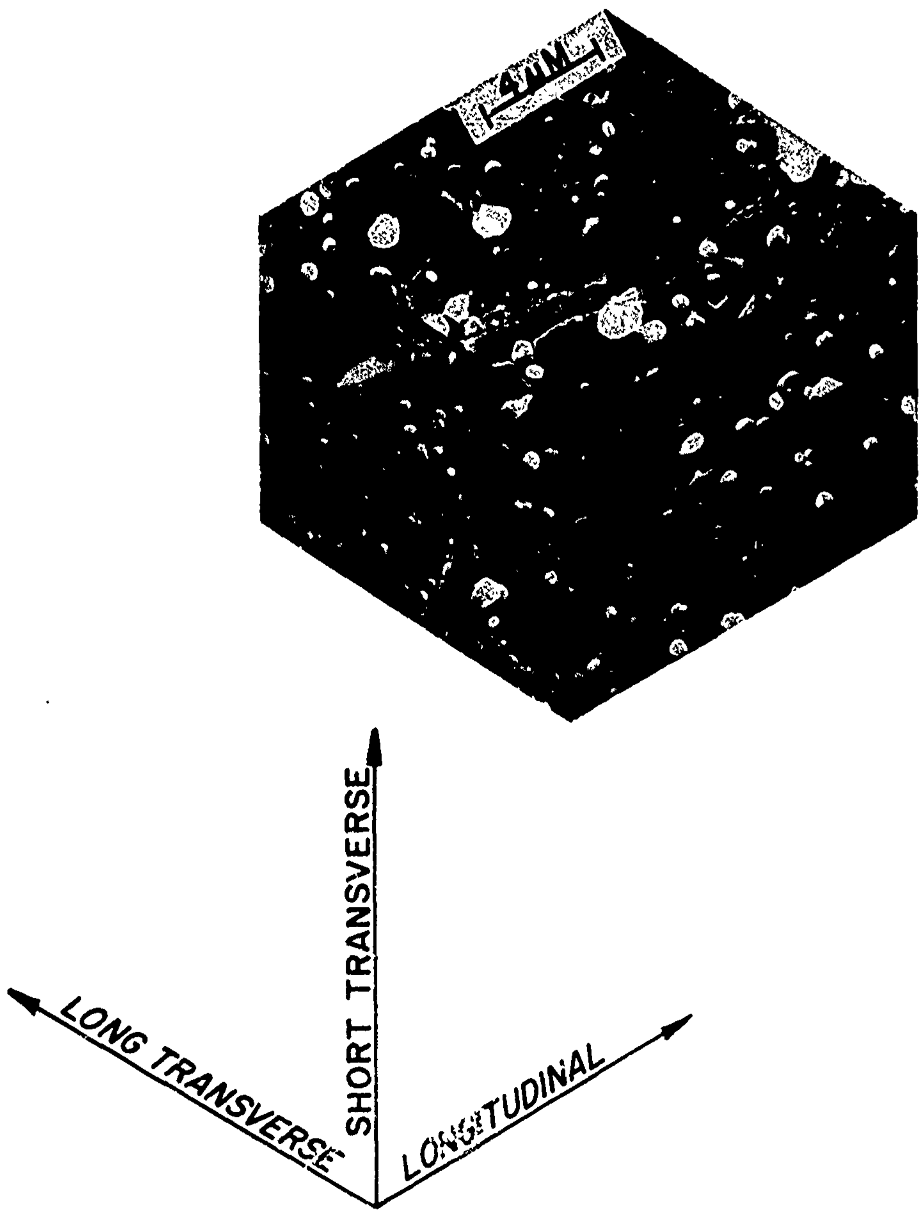
EFFECT OF YIELD STRENGTH AND APPLIED STRESS ON PERCENT SURVIVING 84 DAYS IN ALTERNATE IMMERSION SCC TEST. SHORT TRANSVERSE TENSILE BARS FROM 2" THICK P/M ALLOY AND I/M 7075 HAND FORGINGS.

FIGURE 57



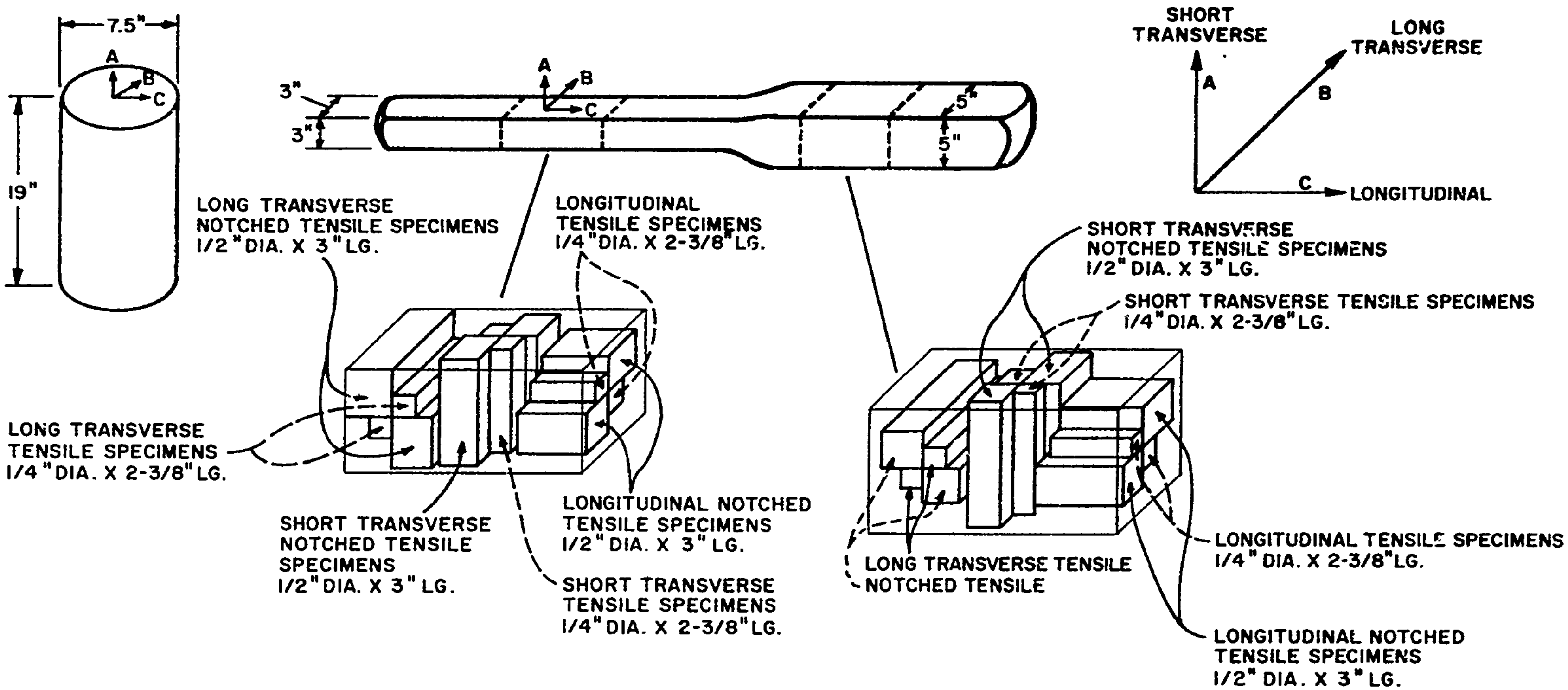
STRUCTURE OF 2 IN. THICK MA65 ALLOY HAND FORGING FROM FINE POWDER (15μM APD). 2000X, BROMINE ETCH, SEM

FIG. 58



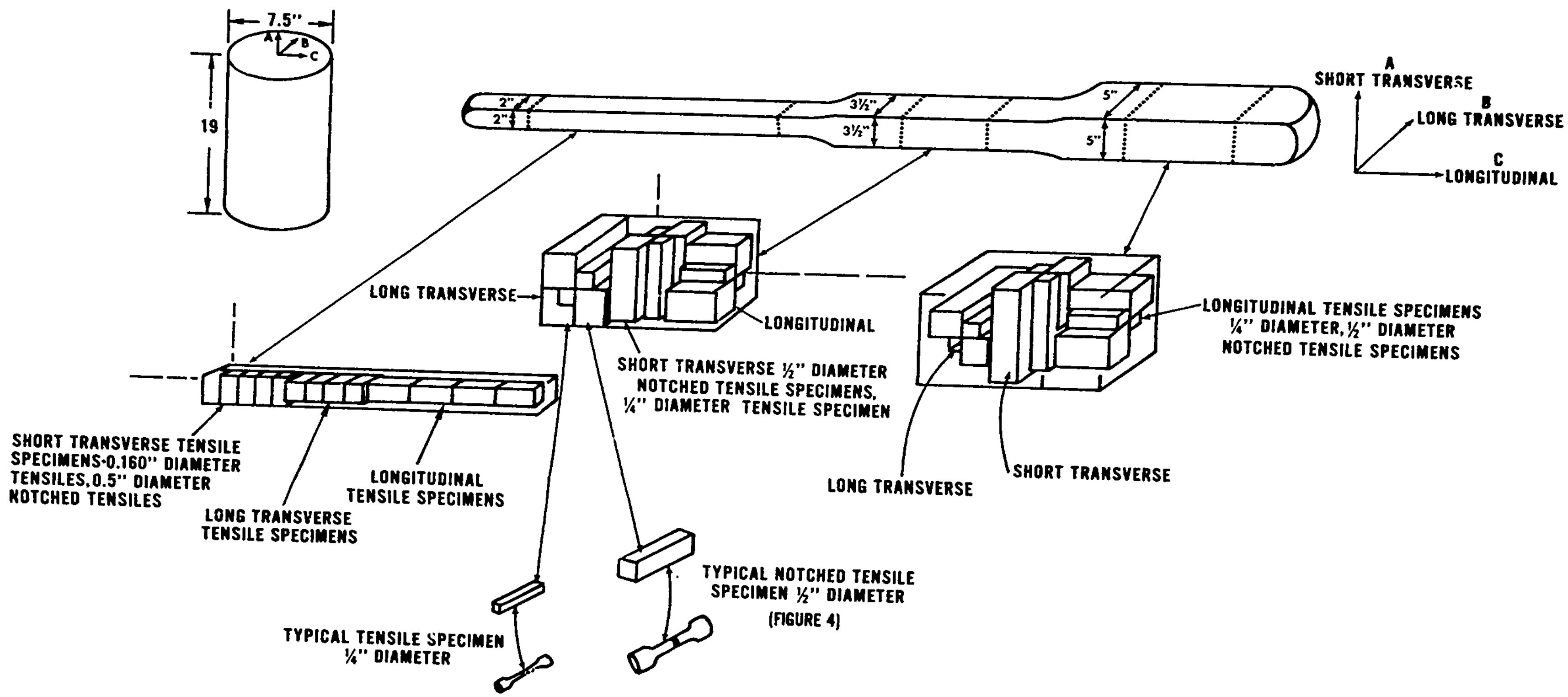
STRUCTURE OF 2 IN. THICK MA67 ALLOY HAND FORGING FROM FINE POWDER (15 µMAPD). WHITE ROUNDED CONSTITUENT IS Co_2Al_9 INTERMETALLIC. 5000X, BROMINE ETCH, SEM

FIG. 59



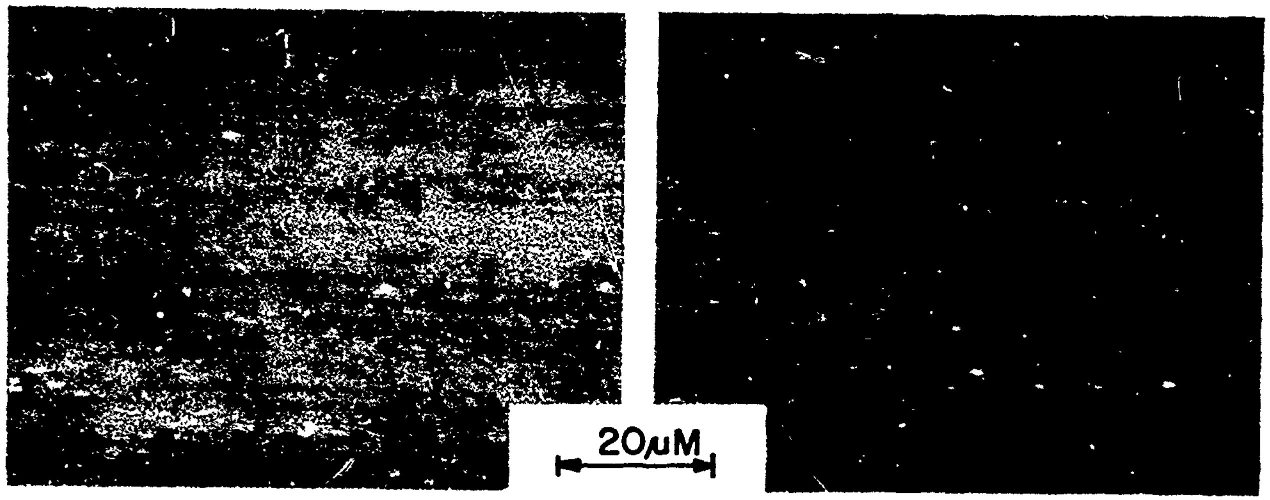
SPECIMEN LAYOUT FOR 3 IN. SQUARE AND 5 IN. SQUARE HAND FORGINGS

FIGURE 60



5" SQUARE HAND FORGING STEPPED DOWN TO 3-1/2" SQUARE AND 2" SQUARE SECTIONS

FIGURE 61

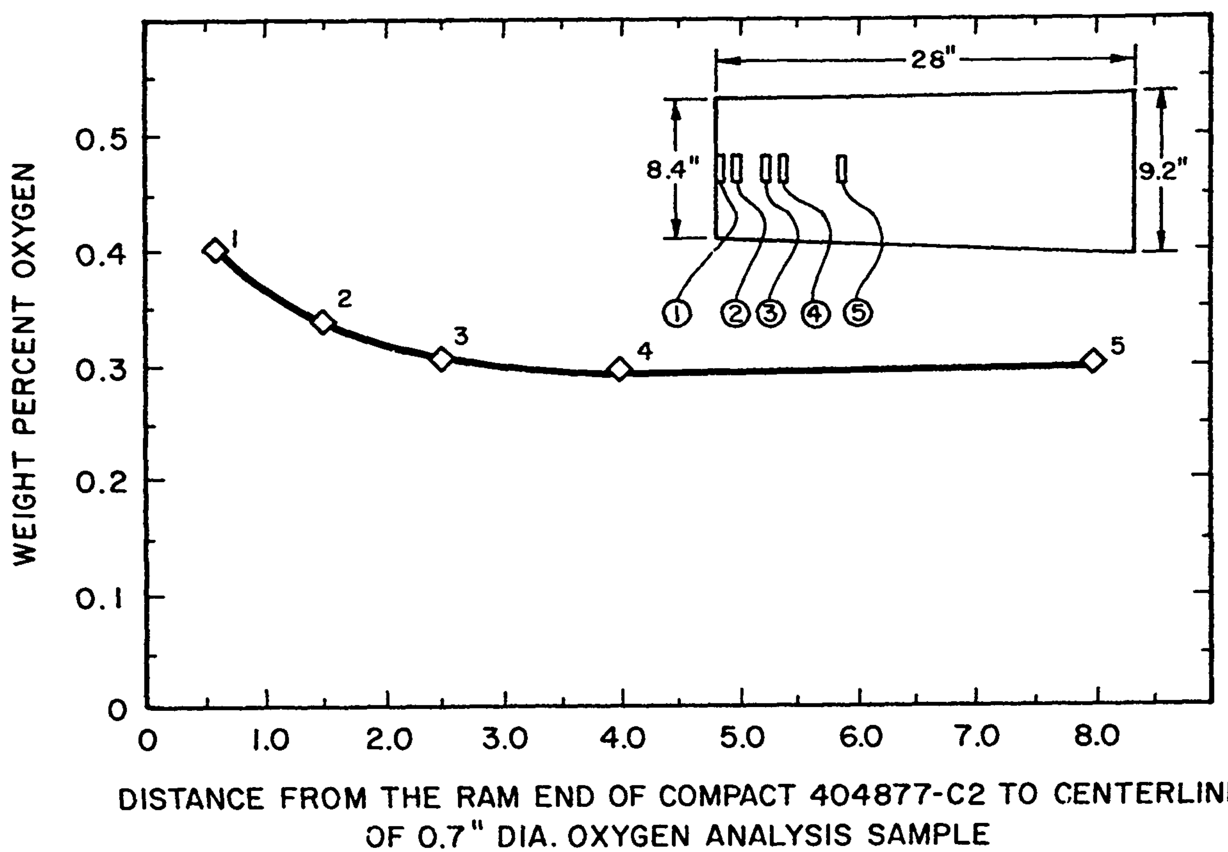


NITROGEN PREHEAT
TOTAL GAS = 3.0 ml/ 100 gms
SHORT TRANSVERSE NTS/YS=1.05

ARGON PREHEAT
TOTAL GAS = 14.6 ml/ 100 gms
SHORT TRANSVERSE NTS/YS= 0.75

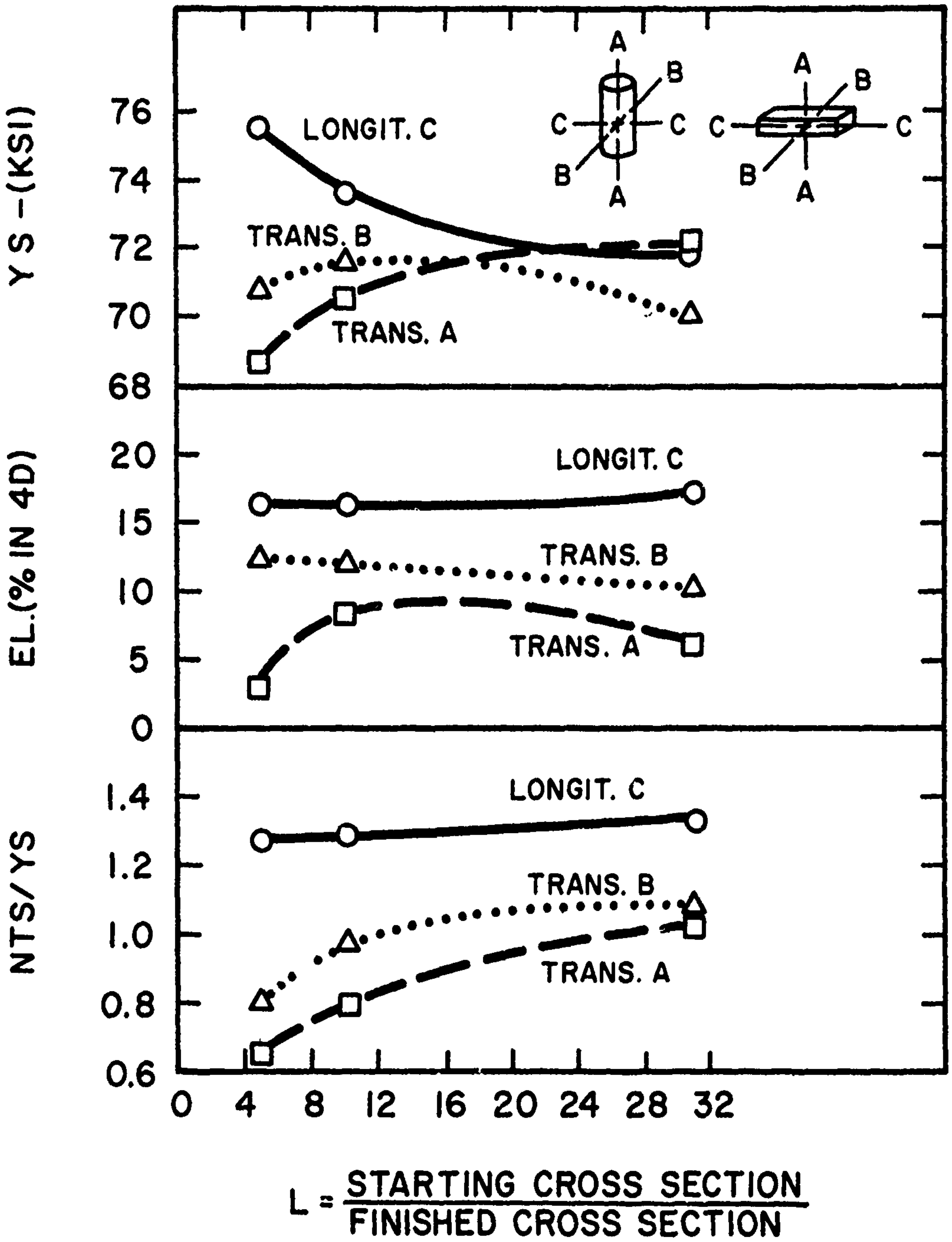
EFFFECT OF PREHEAT GAS ON POROSITY (BLACK) IN FORGINGS FROM HOT-PRESSED COMPACTS. GAS FLOW AT 0.75 CFH/LB OF COMPACT. SEM, 1000X, UNETCHED.

FIG. 62



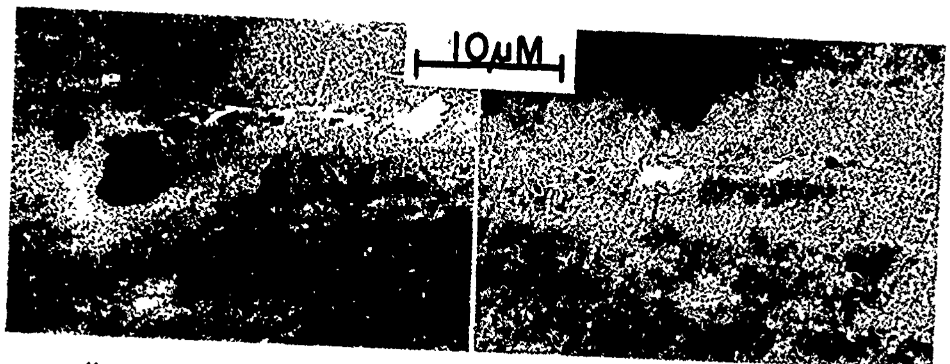
EFFECT OF DISTANCE FROM COMPACT SURFACE ON OXYGEN CONTENT OF A HOT PRESSED MA65 POWDER COMPACT (15.6 μM POWDER) EXPOSED TO ONE DOOR OPENING-CLOSING CYCLE BEFORE REMOVAL FROM ATMOSPHERE FURNACE FOR HOT PRESSING.

FIG. 63



EFFECT OF AMOUNT OF HOT WORK ON
PROPERTIES OF MA65 ALLOY FORGED BAR

FIG. 64

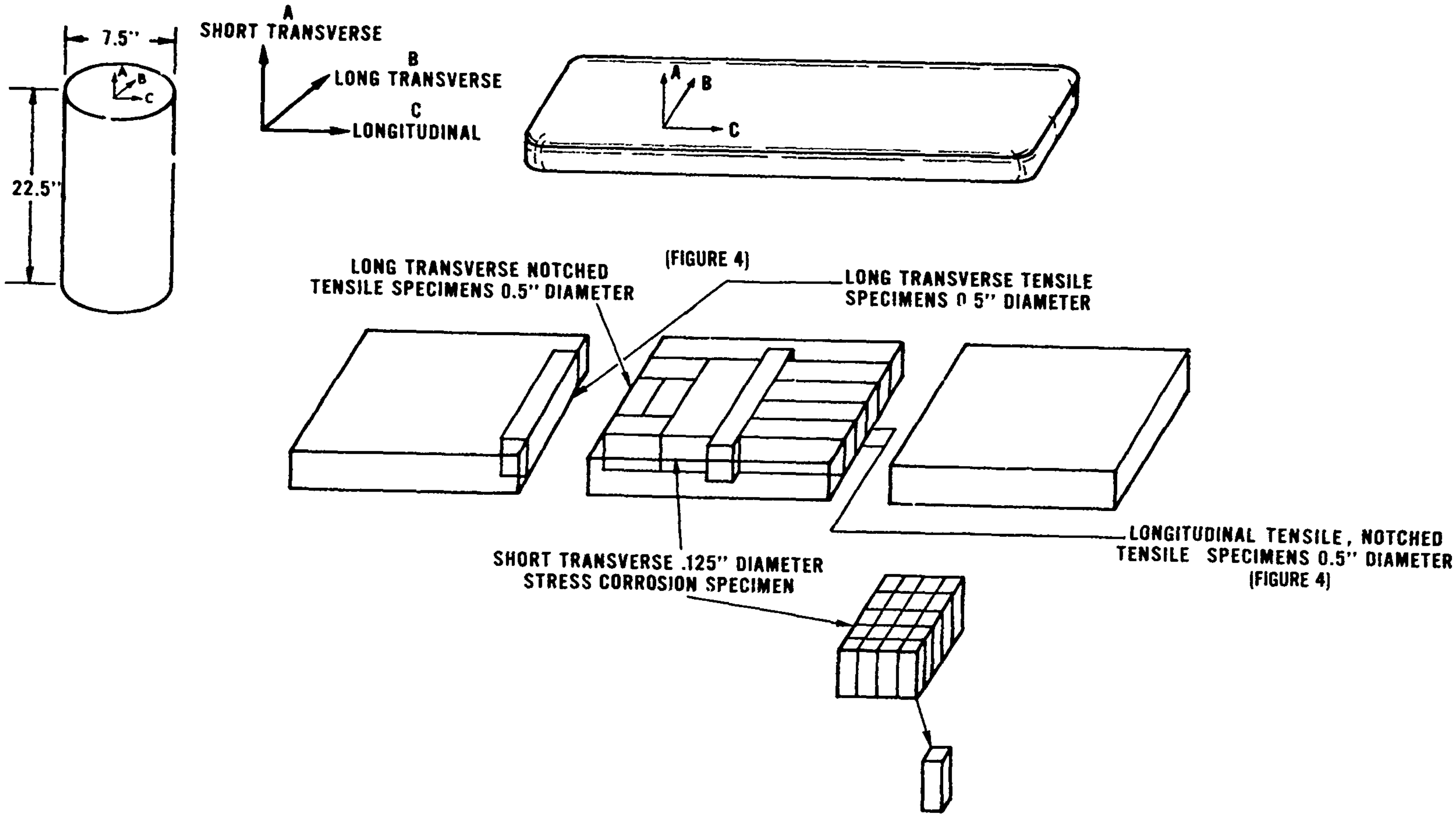


(a) 5" SQUARE FORGING WITH 75% HOT RED.

(b) 3-1/2" SQUARE FORGING WITH 90% HOT RED.

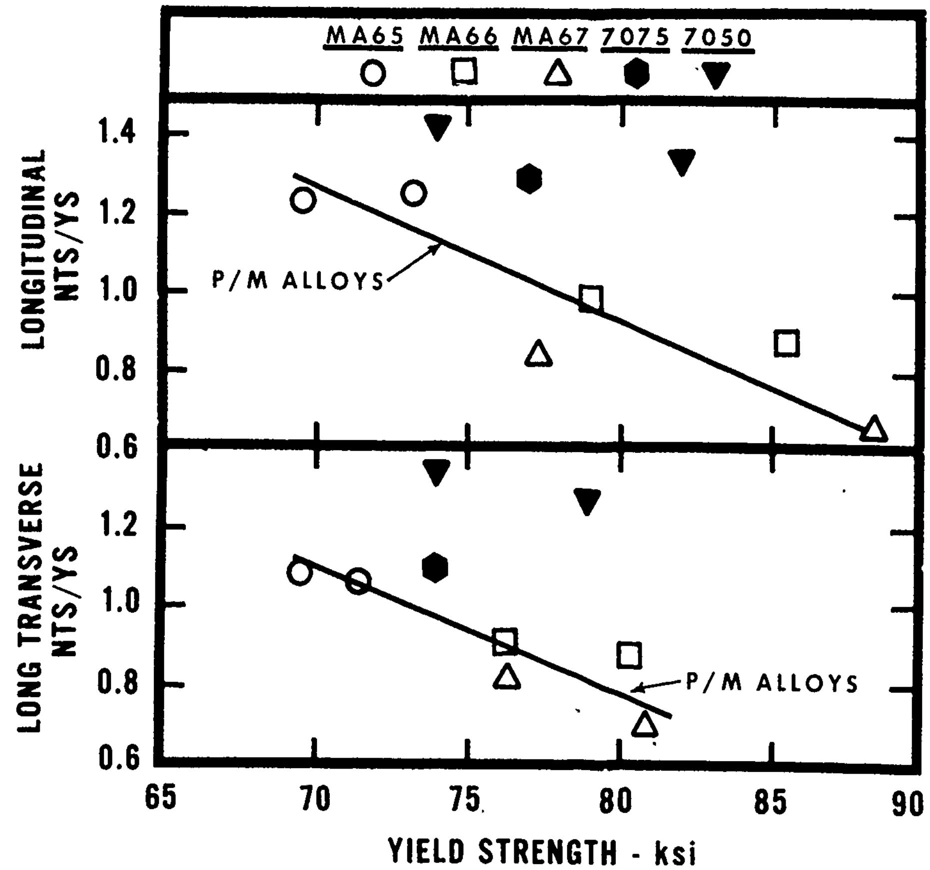
EFFECT OF INCREASING HOT REDUCTION ON POROSITY IN MA65 ALLOY HAND FORGINGS FROM A 170-LB. HOT PRESSED BILLET. 2000 X, UNETCHED SEM.

FIG. 65



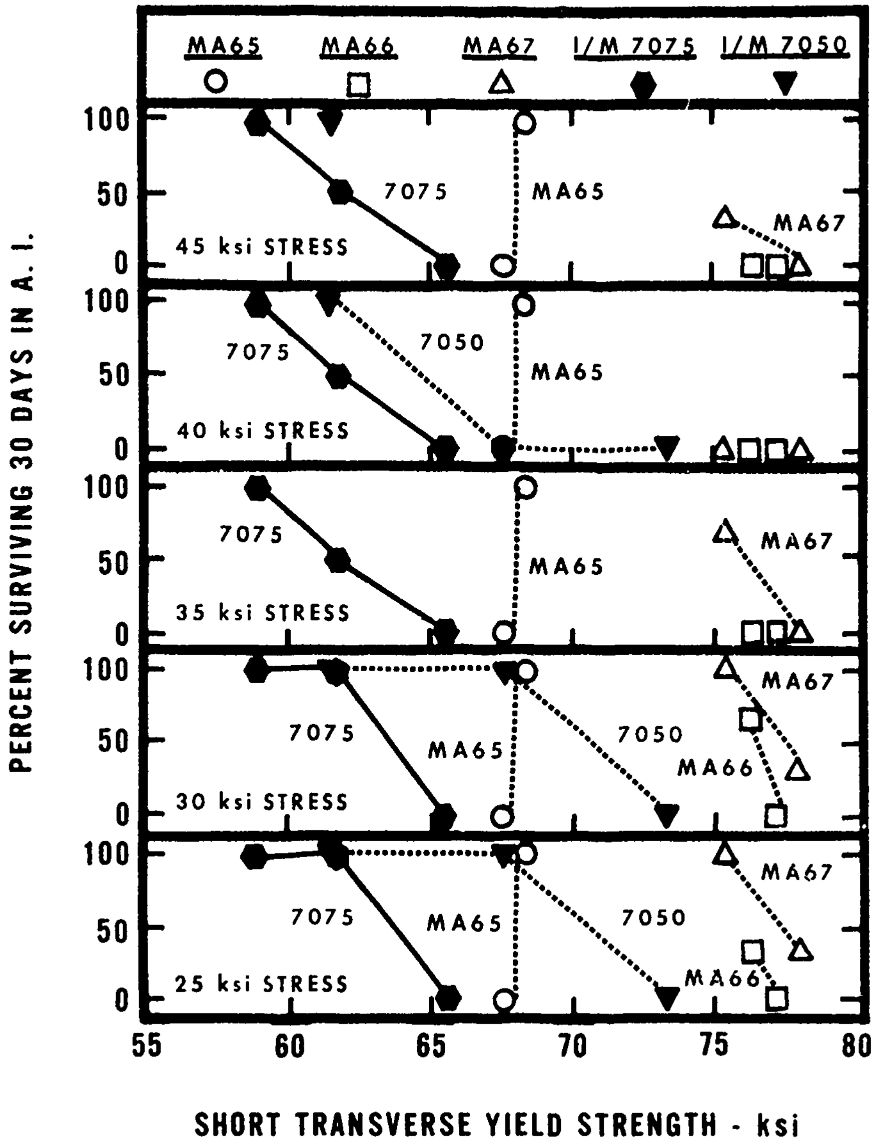
1.5 INCH THICK PLATE SPECIMEN LAYOUT

FIGURE 66



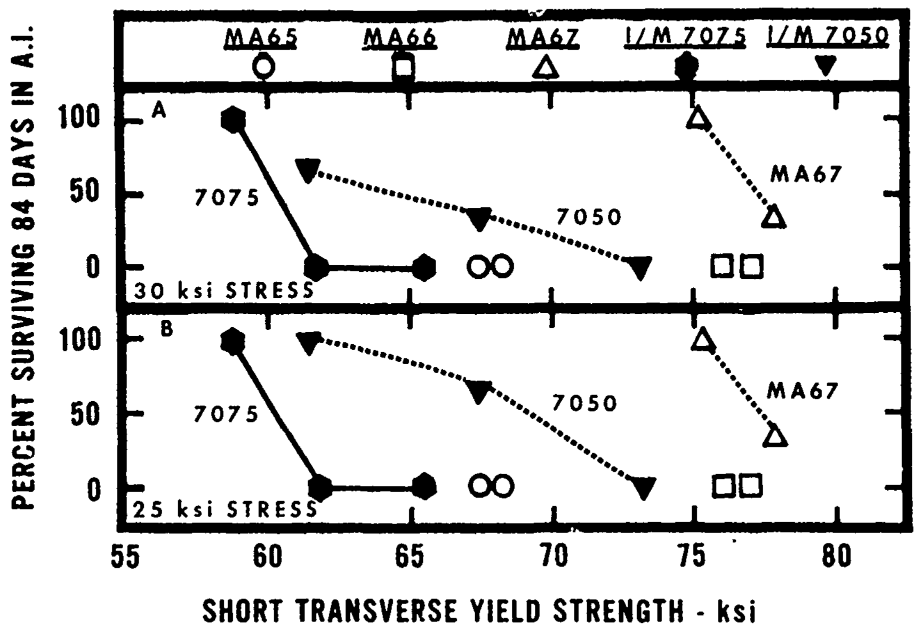
EFFECT OF YIELD STRENGTH ON FRACTURE TOUGHNESS (NTS/YS) OF P/M 1.5" THICK PLATE. COMPARED TO I/M 7075 AND 7050 ALLOY PLATE (FROM REF.16) 2" THICK.

FIGURE 67



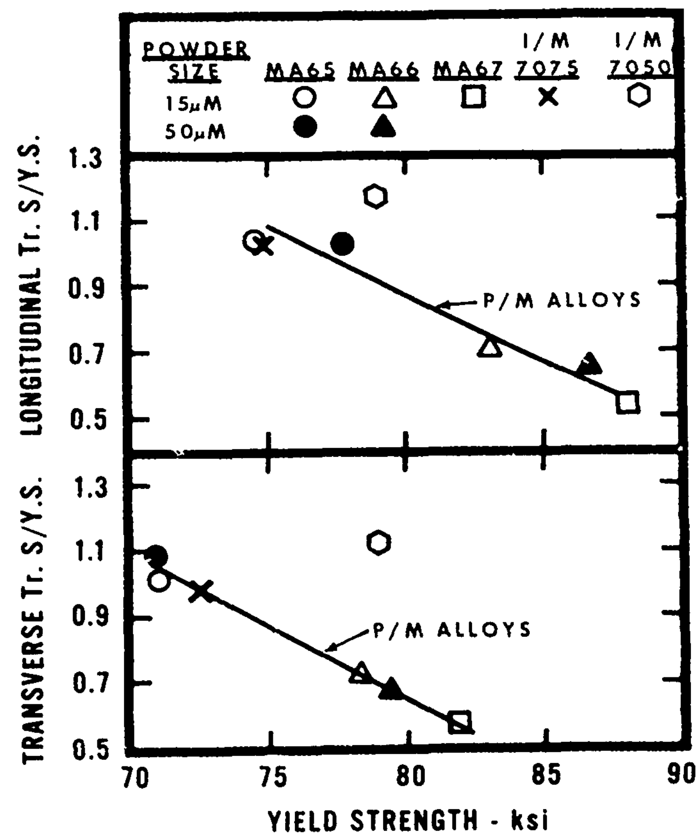
EFFECT OF APPLIED STRESS AND YIELD STRENGTH ON PERCENT SURVIVING 30 DAYS IN ALTERNATE IMMERSION SCC TEST. SHORT TRANSVERSE TENSILE BARS FROM 1.5" THICK P/M AND 2-2.5" THICK I/M 7050 AND I/M 7075 PLATE

FIGURE 68



EFFECT OF APPLIED STRESS AND YIELD STRENGTH ON PERCENT SURVIVING 84 DAYS IN SCC TEST. SHORT TRANSVERSE TENSILE BARS FROM 1.5" P/M AND 2.0–2.5" I/M 7050 AND I/M 7075 PLATE

FIGURE 69



EFFECT OF YIELD STRENGTH ON TEAR STRENGTH/YIELD STRENGTH OF P/M 0.090" SHEET. COMPARED TO I/M 7075 AND 7050 SHEET.

FIGURE 70

TABLE 1, APPENDIX

STRESS-CORROSION PERFORMANCE OF OCTAGONAL EXTRUSIONS IN
NEW KENSINGTON ATMOSPHERE (MATERIAL FROM PHASE II, REF. 5) IN TEST MARCH 19, 1971

Sample No.	Other Elements Wt. %	LYS = 75 ksi Dash No.	TYS ksi	Days to Failure at Stress 42 ksi	25 ksi	LYS = 85 ksi Dash No.	TYS ksi	Days to Failure at Stress 42 ksi	25 ksi	LYS = 95 ksi Dash No.	TYS ksi	Days to Failure at Stress 42 ksi	25 ksi
5.5 Zn-2.0 Mg-1.5 Cu													
398767	0.8 Co	-2	69.3	2 OK[1]	2 OK	None				None			
5.5 Zn-2.0 Mg-2.0 Cu													
398741	None	-2	67.3	2 OK	2 OK	None				None			
398742	0.2 Co	-1	66.8	2 OK	2 OK	None				None			
398743	0.8 Co	-1	68.0	2 OK	2 OK	None				None			
398744	0.8 Fe + Ni	-2	67.5	2 OK	2 OK	None				None			
6.5 Zn-2.4 Mg-1.0 Cu													
398745	None	-4	67.8	2 OK	2 OK	-1	71.0	2 OK	2 OK	None			
398746	0.2 Co	-4	64.8	2 OK	2 OK	-1	63.0	2 OK	2 OK	None			
398747	0.8 Co	-4	68.2	2 OK	2 OK	-1	69.2	2 OK	2 OK	None			
398748	0.8 Fe + Ni	-4	68.8	2 OK	2 OK	-2	74.2	2 OK	2 OK	None			
6.5 Zn-2.4 Mg-1.5 Cu													
398749	None	-4	65.9	2 OK	2 OK	-1	72.8	2 OK	2 OK	None			
398750	0.2 Co	-4	66.3	2 OK	2 OK	-1	70.2	2 OK	2 OK	None			
398751	0.8 Co	-4	56.6	2 OK	2 OK	-1	58.0	2 OK	2 OK	None			
398752	0.8 Fe + Ni	-4	69.2	2 OK	2 OK	-1	73.8	2 OK	2 OK	None			
6.5 Zn-2.4 Mg-2.0 Cu													
398753	None	-4	53.8	2 OK	2 OK	-1	62.3	2 OK	2 OK	None			
398754	0.2 Co	-4	71.0	2 OK	2 OK	-2	69.0	2 OK	2 OK	None			
398755	0.8 Co	-7	67.0	2 OK	2 OK	-3	74.2	2 OK	2 OK	None			
398756	0.8 Fe + Ni	-7	66.4	2 OK	2 OK	-3	74.2	2 OK	2 OK	None			
6.7 Zn-2.4 Mg-2.4 Cu													
398770	None	-4	67.7	2 OK	2 OK	-2	76.4	2 OK	2 OK	None			
398771	0.2 Co	-4	67.3	2 OK	2 OK	-2	75.3	2 OK	2 OK	None			
398772	0.8 Co	-3	68.4	2 OK	2 OK					None			
398773	0.16 Zr	-4	69.2	2 OK	2 OK	-2	76.2	2 OK	2 OK	None			
398774	0.19 Cr	-4	67.6	2 OK	2 OK	-2	75.6	2 OK	2 OK	None			
7.5 Zn-2.6 Mg-1.6 Cu													
398757	None	-4	68.0	2 OK	2 OK	-2	76.0	2 OK	2 OK	None			
398758	0.2 Co	-4	68.6	2 OK	2 OK	-2	77.0	2 OK	2 OK	None			
398759	0.8 Co	-8	69.7	2 OK	2 OK	-5	76.0	2 OK	2 OK	None			
398760	0.8 Fe Ni	-7	70.1	2 OK	2 OK	-5	76.4	2 OK	2 OK	None			
8.9 Zn-2.6 Mg-1.0 Cu													
398761	None	-4	70.0	2 OK	2 OK	-3	77.9	2 OK	2 OK	-1	82.4	257,429	426,OK
398762	0.2 Co	-4	68.6	2 OK	2 OK	-3	74.6	2 OK	2 OK	-1	78.6	415,OK	2 OK
398763	0.8 Co	-4	70.6	2 OK	2 OK	-3	78.0	2 OK	2 OK	-1	83.4	464,520	2 OK
398764	0.8 Fe + Ni	-4	64.4	2 OK	2 OK	-3	56.7	2 OK	2 OK	-1	82.[illegible]	481,OK	2 OK
7.5 Zn-1.6 Mg-3.0 Cu													
398765	0.8 Co	-4	69.0	81,82	147,300	-2	71.7[2]	79,79	493,OK				
398765	0.8 Co	-5	67.3	75,79	193,461								
I/M 7178-T6 Alloy Control													
351376											75.[illegible]	98,117	238,OK
I/M 7075 Alloy Control													
379784		-3	64.6	2 OK	2 OK	-2	71.3	2 OK	2 OK	-1	71.3[2]	103,103	509,OK

NOTES: 1. 2 OK - two specimens intact after 520 days in test.
2. Did not achieve the indicated longitudinal yield strength.

WSC/lmk
9/26/72

TABLE 2, APPENDIX

STRESS-CORROSION PERFORMANCE OF OCTAGONAL EXTRUSIONS
FROM 170 LB. COMPACTS IN NEW KENSINGTON ATMOSPHERE (PHASE III, TABLE 2)

S. No.	Alloy	Powder Size[1] µM	Second-Step Age @ 325 F	LYS ksi	TYS ksi	Days to Failure at Sustained Stress: 45 ksi	40 ksi	35 ksi	30 ksi	25 ksi	Date in Test
404877-E1B	MA65	15.6	None	86.7	72.4	3 OK	3 OK	3 OK	3 OK	3 OK	2-8-72
404877-E1C	MA65	15.6	14 hrs.	76.6	68.2	3 OK	3 OK	3 OK	3 OK	3 OK	2-8-72
404879-E2B	MA65	48.5	None	83.9	73.1	153,2 OK	3 OK	3 OK	3 OK	3 OK	2-8-72
404879-E2C	MA65	48.5	19 hrs.	75.8	70.0	3 OK	3 OK	3 OK	3 OK	3 OK	2-8-72
404880-E3B	MA66	16.5	0.1 hrs.	94.3	78.7	174,2 OK	188,2 OK	196,2 OK	3 OK	3 OK	2-3-72
404880-E3C	MA66	16.5	6 hrs.	84.2	74.2	3 OK	3 OK	3 OK	3 OK	3 OK	4-11-72
404883-E5B	MA67	14.7	0.5 hrs.	95.9	82.8	3 OK	3 OK	3 OK	3 OK	3 OK	2-8-72
404885-E6B	MA67	51.2	3 hrs.	97.4	84.3	160,174,183	174,188 OK	183,2 OK	3 OK	3 OK	2-8-72
				Ingot Metallurgy Control Materials							
405295-5C	7075	Ingot	None	86.9	71.8	194,2 OK	3 OK	3 OK	3 OK	3 OK	2-8-72
405295-5B	7075	Ingot	24 hrs.	73.4	63.9	3 OK	3 OK	3 OK	3 OK	3 OK	11-24-71
405297-3C	7178	Ingot	None	91.2	73.9	182,2 OK	3 OK	3 OK	3 OK	3 OK	2-8-72
405297-3B	7178	Ingot	9.5 hrs.	79.9	70.5	3 OK	3 OK	3 OK	3 OK	3 OK	11-24-71
405241-2C	7001	Ingot	None	98.8	79.3	188,2 OK	3 OK	3 OK	3 OK	3 OK	2-8-72

NOTES: 1. Average Particle Diameter.
2. OK - Intact on August 21, 1972.

WSC/lmk
9/26/72

TABLE 3, APPENDIX

STRESS-CORROSION PERFORMANCE OF P/M DIE FORGINGS (DIE 9078)
IN NEW KENSINGTON ATMOSPHERE (PHASE III - SEE TABLES 49, 50)

Sample No.[1]	Alloy	Quench Water Temp. °F	Second-Step Age[2] @ 325 F	Flange Properties LYS ksi	Flange Properties STYS ksi	Short-Transverse Specimens[4] Days to Failure at Sustained Stress 45 ksi	40 ksi	35 ksi	30 ksi	25 ksi	Date in Test
404877-D1F	MA65	80	None	74.4	69.0	3 OK[3]	3 OK	3 OK	3 OK	3 OK	1-12-72
404877-D2F	MA65	150	None	66.4	59.1	3 OK	3 OK	3 OK	3 OK	3 OK	1-12-72
404880-D3F	MA66	80	None	78.5	75.9	158,196,207	3 OK	203,215,OK	3 OK	3 OK	1-12-72
404880-D3R	MA66	80	6 hrs.	81.8	74.4	3 OK	3 OK	3 OK	3 OK	3 OK	3-9-72
404880-D4F	MA66	150	None	76.4	65.2	3 OK	3 OK	3 OK	3 OK	3 OK	1-12-72
404883-D5F	MA67	80	None	88.3	79.3	132,158,OK	188,232,OK	130,151,OK	3 OK	3 OK	1-12-72
404883-D5R	MA67	80	6 hrs.	83.1	77.6	3 OK	3 OK	3 OK	3 OK	3 OK	3-9-72
404883-D6F	MA67	150	None	77.2	71.6	167,2 OK	3 OK	3 OK	3 OK	3 OK	1-12-72
				Ingot Metallurgy Control Material							
405295-2F	7075	80	None	82.9	70.6	35,53,53	12,49,100	53,167,OK	118,200,OK	209,2 OK	1-12-72
405295-2R	7075	150	None	69.1	58.6	33,126,130	35,78,186	41,59,151	118,145,223	193,2 OK	1-12-72

NOTES:
1. All P/M forgings from 15μM APD Powders.
2. First-step aged 24 hours @ 250 F.
3. OK = specimen intact through 8-31-72.
4. Specimens across parting plane in flange.

WSC/lmk
9/26/72

TABLE 4, APPENDIX

STRESS-CORROSION PERFORMANCE OF P/M HAND FORGINGS (2" THICK) IN NEW KENSINGTON ATMOSPHERE

Sample No.	Alloy	Powder Size[1] μM	Quench Water Temp. °F	Second-Step Age[2] @ 325 F	Forging Properties LYS ksi	Forging Properties STYS ksi	Short-Transverse Specimens, Days to Failure at Sustained Stress: 45 ksi	40 ksi	35 ksi	30 ksi	25 ksi	Date in Test
404877-M2B	MA65	15.6	80	None	74.2	62.2	172, 2 OK[4]	3 OK	3 OK	3 OK	3 OK	3-9-72
404877-M2C	MA65	15.6	80	4 hrs.	68.0	62.5	3 OK	3 OK	3 OK	3 OK	3 OK	11-24-71
404877-M1C	MA65	15.6	150	None	69.6	65.0	140,2 OK	3 OK	3 OK	3 OK	3 OK	3-9-72
404877-M3C	MA65	15.6	180	None	66.7	63.2	159,2 OK	3 OK	3 OK	3 OK	3 OK	3-9-72
404879-N2C	MA65	48.5	80	4 hrs.	71.8	70.0	237,2 OK	235,272,OK	258,2 OK	3 OK	3 OK	11-24-71
404880-M8A	MA66	16.5	80	None	80.0	68.2	102,175,OK	3 OK	3 OK	3 OK	3 OK	3-9-72
404880-M8B	MA66	16.5	80	2 hrs.	76.8	67.9	3 OK	3 OK	3 OK	3 OK	3 OK	11-24-71
404880-M7B	MA66	16.5	150	None	76.2	70.6	172,2 OK	154,2 OK	3 OK	3 OK	3 OK	3-9-72
404880-M9C	MA66	16.5	180	None	69.8	68.4	169,2 OK	3 OK	3 OK	3 OK	3 OK	3-9-72
404882-M10B	MA66	49.3	80	4 hrs.	76.9	(3)	181,181,218	98,188,207	204,216,241	216,241,258	3 OK	11-24-71
404883-M13A	MA67	14.7	80	None	81.8	72.0	3 OK	132,2 OK	144, 2 OK	3 OK	3 OK	3-9-72
404883-M13B	MA67	14.7	80	2 hrs.	76.4	69.2	3 OK	3 OK	3 OK	3 OK	3 OK	11-24-71
404883-M12B	MA67	14.7	150	None	74.8	70.6	120, 2 OK	3 OK	3 OK	3 OK	3 OK	3-9-72
404883-M14C	MA67	14.7	180	None	70.6	66.4	3 OK	3 OK	3 OK	3 OK	3 OK	3-9-72
Ingot Metallurgy Control Material												
405295-Q2	7075	Ingot	80	None	69.9	59.8	21,60,68	74,88,95	83,88,99	83,95,109	102,109,118	3-9-72

NOTES:
1. Average Particle Diameter from Fisher sub sieve sizer.
2. First-step aged 24 hours @ 250 F.
3. Failed at less than 0.2% offset.
4. OK = specimen intact through 8-31/72.

WSC/lmk
9/26/72

TABLE 5, APPENDIX

STRESS-CORROSION PERFORMANCE OF P/M PLATE (1-1/2" THICK)
IN NEW KENSINGTON ATMOSPHERE (PHASE III - SEE TABLES 80, 81)

Sample No.[1]	Alloy	Second-Step Age[2] @ 325 F	Plate Properties LYS ksi	Plate Properties STYS ksi	Short-Transverse Specimens, Days to Failure at Sustained Stress: 45 ksi	40 ksi	35 ksi	30 ksi	25 ksi	Date In Test
404877-K1B	MA65	None	73.2	67.6	50,65,272	61,194,OK	47,47,200	35,207,OK	3 OK	11-24-71
404877-K1C	MA65	4 hrs.	69.6	68.3	3 OK	3 OK	3 OK	3 OK	3 OK	11-24-71
404880-N3A	MA66	None	85.5	77.2	153,200,200	173,207,244	194,214,258	231,244	3 OK	11-24-71
404880-N3B	MA66	2 hrs.	79.1	76.3	266,2 OK	231,237,OK	3 OK	3 OK	3 OK	11-24-71
404883-J5A	MA67	None	88.4	78.0	91,153,179	179,181,181	141,181,188	179,194,OK	232,247,OK	11-24-71
404883-J5B	MA67	2 hrs.	77.3	75.4	3 OK	249,2 OK	3 OK	3 OK	3 OK	11-24-71
Ingot Metallurgy Control Material[3]										
399479-B[4]	7075	None	79.8	65.6	43,44,44,44,55	44,56,61,91,97	56,56,61,66,73	44,56,82,87,118	44,91,106,111,111	11-24-71
399480-4	7075	10 hrs.	63.8	61.8	2 OK	2 OK	2 OK	2 OK	2 OK	4-11-72
399481-R[5]	7075	24 hrs.	59.3	58.9	5 OK	5 OK	5 OK	5 OK	5 OK	11-24-71

NOTES:
1. All P/M plate from 15μM APD powders.
2. First-step aged 24 hours @ 250 F.
3. 2.5" thick plant produced plate, 7075-T651, laboratory second-step aged.
4. Includes 2 samples per stress marked 413364-B, in test 4-11-72.
5. Includes 2 samples per stress marked 413363-R, in test 4-11-72.
6. OK = Specimens intact through 8-23-72.

WSC/lmk
9/26/72

DISTRIBUTION LIST

Commanding General
U.S. Army Materiel Command
Attn: AMCPR-PI
AMCRD-TC, Mr. L. Croan
Washington, D.C.

Commanding General
U.S. Army Missile Command
Attn: AMSMI-ID, Mr. J. E. Kirshtein
AMSMI-IEP, Mr. Giles Wetherill
Redstone Arsenal, Alabama 35809

Commanding General
U.S. Army Munitions Command
Attn: AMSMU-MT-PC, Mr. D. Griffin
AMSMU-RE-E, Mr. W. G. McDaniel
AMSMU-CG, Mr. R. M. Schwartz
AMSMU-RE-R, Dr. J. Erway
Dover, New Jersey 07801

Commanding General
U.S. Army Weapons Command
Attn: AMSWE-RET, Mr. W. Kisner
AMSWE-PPR, Mr. V. X. Walter
AMSWE-PPR, Mr. G. Hall
Rock Island Arsenal, Illinois 61201

Commanding General
U.S. Army Electronics Command
Attn: AMSEL-RD-GS, Mr. Stanely Mader
Fort Monmouth, New Jersey 07703

Commanding General
U.S. Army Aviation Materiel Command
Attn: AMSAV-PRI, Mr. J. Thorp
AMSAV-PPL, Mr. F. Matthews
AMSAV-PRI, Mr. W. L. Breckinridge
P. O. Box 209, Main Office
St. Louis, Missouri 63166

Commanding General
U.S. Army Mobility Equipment Command
Attn: AMSME-PLA, Mr. J. J. Murphy
AMSME-PLA, Mr. M. W. Schriet
4300 Goodfellow Blvd.
St. Louis, Missouri 63120

Commanding General
U.S. Army Tank Automotive Command
Attn: AMSTA-RCM.1, Mr. D. Phelps
AMSTA-RCM.1, Mr. E. Mortiz
Warren, Michigan 48090

Dr. I. Cadoff
New York University
University Heights
Bronx, New York 10452

Professor M. Flemings
Massachusetts Institute of Technology
Room 35-316
Cambridge, Massachusetts

Dr. Scrade Radtke
International Lead Zinc Institute
292 Madison Avenue
New York, New York 14305

Dr. Jerome Weiner
Columbia University
New York, New York 10027

Commanding Officer (35)
Frankford Arsenal
Attn: L7000, D. Kleppinger, 149/2
Philadelphia, Pennsylvania 19137

Commanding Officer
U. S. Army MERDC
Attn: Mr. William H. Baer
SMEFB-MMR, Building 363
Fort Belvoir, Virginia 22060

U.S. Army Small Arms Systems Agency
Aberdeen Proving Grounds
Attn: AMXAA-AC
Aberdeen, Maryland 21005

Mr. H. C. Turner
Branch Manager, Metallic Materials
Dept. 372, Building 33
McDonald Aircraft Corporation
P. O. Box 516
St. Louis, Missouri 63166

Commanding Officer
Picatinny Arsenal
Attn: Material Engineering Lab
Dr. Benner
Dover, New Jersey 07801

DISTRIBUTION LIST (CONTINUED)

Director
U.S. Army Production Equipment Agency
Attn: AMXPE-MT, Mr. H. Holms
Rock Island, Illinois 61201

Defense Documentation Center (20)
Cameron Station
Alexandria, Virginia 22314

Defense Materials Information Center
Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201

Air Force Materials Laboratory
Air Force Systems Command
Attn: MATF, Mr. H. Johnson
Mr. I. Perlmutter, Chief
Metals & Ceramics Division
Wright Patterson Air Force Base
Dayton, Ohio 45433

Mr. Carson L. Brooks
Reynolds Metals Company
4th and Canal Streets
Richmond, Virginia 23220

Dr. Robert S. Busk
Dow Chemical Company
Midland, Michigan 48640

Dr. LaVerne W. Eastwood
Olin Mathieson Chemical Corporation
P. O. Box 164
Hannibal, Ohio 43931

Dr. G. Irwin
Lehigh University
Bethlehem, Pennsylvania 18018

Dr. J. B. Hess
Dept. of Metallurgical Research
Kaiser Aluminum & Chemical Corp.
Spokane, Washington 99215

Dr. William Rostoker
University of Illinois
College of Engineering
Box 4348
Chicago, Illinois 60680

DISTRIBUTION LIST (CONTINUED)

Commanding Officer
U.S. Army Materials & Mechanics Res. Center
Attn: AMXMR-TX, Mr. E. Hegge
AMXMR-TX, P. P. A. Carbonaro
AMXMR-TX, Dr. Priest
Watertown, Massachusetts 02172

Commanding Officer
Savanna Army Depot
Attn: AMXSV-EN
AMC Ammunition Center
Savanna, Illinois 61074

Commanding Officer
Fort Detrick
Attn: SMUFD, Mr. H. M. Meier
Frederick, Maryland 21701

Commanding Officer
Rock Island Arsenal
Attn: SWERI-PPE-5311, Mr. J. A. Fox
Metallurgy Laboratory
Rock Island Arsenal, Illinois 61201

Commanding Officer
U.S. Army Aeronautical Depot Maintenance Center
Attn: SAVAE-EFT, Mr. J. Dugan
Corpus Christi, Texas 78419

Project Manager, General Purpose Vehicles
Michigan Army Missile Plant
Attn: AMCPM-GPV-QV, Mr. E. A. Cowgill
Warren, Michigan 48090

Commanding Officer
Watervliet Arsenal
Attn: SWEWV-PPP-WP, Mr. L. Slawsky
Watervliet, New York 12189

National Aeronautics & Space Administration
Attn: G. C. Deutsch
1512 H Street N.W.
Washington, D. C. 20546

NASA
George C. Marshall Space Flight Center
Attn: Mr. William A. Wilson, M-F&AR-M
Huntsville, Alabama 35800

NASA
Lewis Flight Propulsion Lab.
Attn: Library
2100 Brookpar Road
Cleveland, Ohio 44135

DISTRIBUTION LIST (CONTINUED)

Commanding Officer
Edgewood Arsenal
Attn: Mr. Schneck
Materials Engineering Lab
Edgewood, Maryland 21010

Mr. R. H. Brown
1411 Pacific Avenue
Natrona Heights, Pennsylvania 15065

Commander
Naval Air Systems Command
Attn: Mr. R. Schmidt
Code AIR-52031A
Department of Navy
Washington, D. C. 20360

Commander
Naval Air Systems Command
Attn: Mr. Dale Meyn
Code 6322
U. S. Naval Research Lab
Washington, D. C. 20390

Mr. N. Tupper
Air Force Flight Dynamics Laboratory (FBA)
Wright-Patterson Air Force Base
Ohio 45433

GLOSSARY

A.I.	- Accelerated Stress-Corrosion Cracking Test - Alternate Immersion in 3.5% NaCl solution per Federal Test Method 823.
APD	- Average Particle Diameter from Fisher Sub-Sieve Sizer.
AVAC	- Process involving live vacuum preheating a powder compact in a welded aluminum can followed immediately by sealing the compact in a can under conditions where retention of the vacuum in the can was questionable. Canned compact was hot pressed and/or hot worked in a vacuum of unknown quality.
CANAR	- Process of preheating a powder compact in flowing argon gas in a welded aluminum can followed immediately by hot pressing of the canned compact and hot working.
CANIT	- Process of preheating a powder compact in flowing nitrogen gas in a welded aluminum can followed immediately by hot pressing and/or hot working of the canned compact.
Coarse	- Product made from coarse powder with 50 μM average particle diameter.
CWQ	- Cold-water quench after solution heat treatment.
D.C.	- Direct Chill Cast Ingot.
El.	- Percent elongation in 4 diameters.
ExCO	- Accelerated Exfoliation Corrosion Test - 48 hours total immersion in a 4 molar NaCl, 0.5 molar potassium nitrate and 0.1 molar HNO_3 solution.
FCE	- Process of preheating a powder compact in flowing argon gas in an atmosphere furnace, removing the compacts individually from the furnace, transporting the hot compact (in air) to a press for hot pressing to essentially full density prior to hot working. Furnace atmosphere diluted with air on each door opening--no vestibule to prevent argon atmosphere dilution with air.
Fine	- Product made from fine powder with 15 μM average particle diameter.

GLOSSARY (CONTINUED)

I/M - Products fabricated from direct chill cast ingot.

Irregular - Powder shape resulting from atomizing with compressed air and collecting in air. See "Regular."

K_{Ic} - Plane-strain stress intensity factor, a critical measure of the fracture toughness of a material.

ksi - 1000-lbs per square inch.

L, Long. - Longitudinal.

LT - Long-transverse.

LYS - Longitudinal yield strength.

N.A. - Natural age at room temperature.

NTS/YS - Notched tensile strength/tensile yield strength.

P/M - Products fabricated from atomized alloy powder.

Press. - Pressure in units of 1000 psi = 1 ksi.

Regular - Rounded powder shape resulting from atomizing with an inert gas aspirating the molten metal and collecting and conveying the powder in air.

RET - Process of preheating a powder compact in flowing nitrogen (or argon) gas in a recloseable retort followed immediately by removing the compact from a retort at the press for hot pressing and/or hot working.

SCC - Stress-corrosion cracking.

SEM - Scanning Electron Micrograph.

SHT - Solution heat treatment.

ST - Short-transverse.

STYS - Short-transverse yield strength.

T6 - Aged 24 hours at 250 F.

Temp. - Temperature in °F.

TrS/YS - Tear strength (Kahn-tear test)/tensile yield strength.

GLOSSARY (CONTINUED)

TYS - Transverse yield strength.

VAC - Process of live vacuum preheating a powder compact in a welded aluminum can to 1000 F, followed immediately by sealing the evacuation line to retain the vacuum and hot pressing to essentially full density.

YS - Yield strength.